THE

ENGINEER'S ENCYCLOPÆDIA

CONTAINING A HISTORY OF THE DISCOVERY AND APPLICATION OF STEAM, WITH ITS PRACTICE AND ACHIEVEMENTS FROM THE EARLIEST PERIOD TO THE PRESENT TIME.

THE WHOLE FORMING A PRACTICAL GUIDE TO

THE MOST RECENT APPROVED METHODS OF CONSTRUCTION, WITH EXAMPLES DRAWN TO SCALE IN SIMPLE WORKSHOP FORM.

WITH RULES AND FORMULÆ RELATING TO

BOILERS, STATIONARY ENGINES, MARINE ENGINES, LOCOMOTIVES, AND THE TREATMENT AND REGULATION OF STEAM.

A NEW EDITION CONTAINING A COPIOUS APPENDIX

DESCRIPTIVE OF MACHINE TOOLS, HAMMERS, ELECTRIC ENGINEERING DYNAMOS, MAGNETS, MOTORS AND OTHER APPLIANCES OF ELECTRICITY, ETC.

BY

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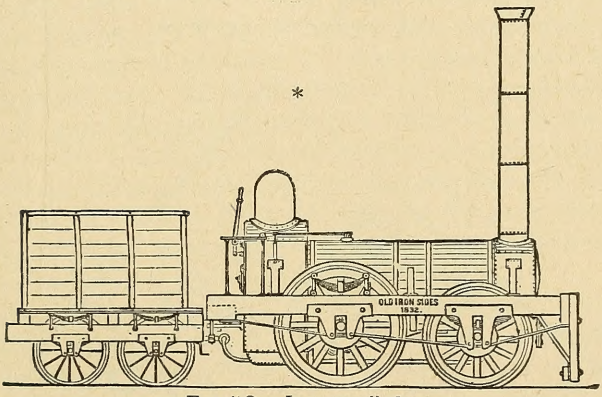
Author of "Modern Workshop Practice." *Author of "Principles of Mechanics," etc.*



THE "OLD IRONSIDES," 1832.

ILLUSTRATED BY OVER SIX HUNDRED ENGRAVINGS IN THE TEXT AND A SERIES OF SEPARATE PLATES.

PHILADELPHIA:
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PREFACE.

THE object of this publication is to supply the practical Engineer and Mechanic with a trustworthy guide to the varied operations of the Workshop in a convenient form and at a moderate price. It is written by practical men, well acquainted with the operations which they describe, and seeks to convey to the workman detailed directions regarding his work in language such as he is familiar with, and at the same time to state clearly the higher principles upon which these operations are based, and on which they depend for success.

The importance of this book for those engaged in all branches of Engineering, etc., will at once be seen by an examination of the Summary of Contents. From this summary may also be gathered a general idea of the scope of the work, and of the manner in which the various subjects are treated. After a brief notice of Coal and Coal-mining, the author discusses the forms of Boilers, their construction, the use of Steel and the treatment of Steam; the Land or Stationary Engine in its many forms and uses; the Marine Engine of the present day as well as that of fifty years ago, and the important subject of the Screw Propeller; the Locomotive Engine and Tender, British and American, including details of recent improvements and special forms made for different railways. Numerous Tables, Rules and Formulæ are given throughout the book, rendering it a useful companion in the counting-houses and designing rooms of locomotive works and machine shops.

Besides the useful working drawings, of which there are nearly 700 in all, there are sixteen large folding plates of important examples and twenty-five tables for reference and instruction in every possible requirement for calculation. These illustrations teach through the eye in a clear and perspicuous manner. They are executed without shade lines in order that they may all the better meet the requirements of practical men.

This book will be found a most useful assistant not only to those charged with the duty of carrying on and superintending work, but also to intelligent workmen who seek to understand the best modes of performing the operations in which they are engaged, as well as to all learners, whose aim should be to acquire thoroughly principles as well as hand

skill, and so qualify themselves for the higher positions of their trades. It will also be found of great service as a means of preparing those who desire to pass the special examination recently proposed by the Trades Union Congress in England and Scotland to be instituted for men having charge of steam engines or boilers. As an example of the importance of this subject to all who are in any way interested in or have the care of Boilers, it was stated in the House of Commons, on the second reading of the *Boilers Explosion Bill* (22d Feb., 1882), that through Boiler Explosions one man was killed on an average every four days, and two thousand persons maimed from the same cause during the past few years.

In order that the reader may thoroughly understand all the subject, the practical part of the work is prefaced by a thorough and concise history of the discovery and progress of perfecting the application of steam to its present power and perfection.

The story of the glimpse that the ancients had of its possibilities, 130 B. C., in the Æolipile of Hero, and next the somewhat uncertain statement that Blaxo de Garay showed a steamboat in the harbor of Barcelona in 1543; then Solomon de Caus in 1615, Giovanni Branca in 1629, the Marquis of Worcester in 1663, Papin, the real discoverer of the first practical step, in 1689, Savary in 1699, and Newcomen in 1705, who improved on Papin and Savary, and by using both air and steam first applied the power to pumping water out of mines, until Watt, in 1765, on getting one of Newcomen's models to repair, made the discovery of improvements which have revolutionized the industries and commerce of the world.

The story of its practical adoption in steamship propulsion and in railroad locomotion will be found circumstantially related, and the share of each; the two Stephensons, Trevethick, Symington, Murdoch, Ericsson and others of England, and Oliver Evans, Fulton, John Fitch, Stevens, Long, Baird, Norris, Harrison, Eastwick, Baldwin, etc., of America, all receive due notice and their record of improvements.

This plan of minutely tracing and describing each successive improvement must prove both interesting and instructive, because the student interested in these details, when fully informed as to how the present perfection has been won step by step, will be better able to understand the present condition of Modern Mechanics, and in his turn may conclude that improvements are yet possible.

CONTENTS OF THE HISTORY OF STEAM.

ILLUSTRATIONS IN THE HISTORY OF STEAM.

THE HISTORY OF STEAM
AND ITS PRACTICAL APPLIANCES.

JAMES WATT, the improver of the steam-engine, was born at Greenock in Renfrewshire, Scotland, on the 19th of January, 1736. He was the descendant of a family the members of which, for several generations, had exhibited no small degree of ability. His great-grandfather was the proprietor and farmer of a small estate in Aberdeenshire; but taking part in the insurrection headed by Montrose, he was killed in one of the battles then fought, and his little property was confiscated. This person's son, Thomas Watt, was but an infant at the time of his father's death. Left almost destitute by that

event, he was taken care of by relations till he grew up, when, manifesting a decided taste for mathematical science, in which he had already attained great proficiency, he removed to Greenock, and settled there as a teacher of navigation, surveying, and general mathematics. In this situation he acquired great reputation, and became one of the most respected and influential persons in the neighborhood, filling for several years the office of baron-bailie, or chief magistrate of the burgh of Crawford's Dike. He died in 1734, at the advanced age of ninety-two years, and was buried in the West Churchyard of Greenock, where, in the inscription on his tombstone, he is styled "Professor of Mathematics." He had two sons, John and James; the elder of whom inherited his father's mathematical talent, and followed his profession, first at Ayr, and afterwards in Glasgow, where he also enjoyed a large business as a surveyor. Among his qualifications was that of drawing with very great neatness and accuracy. He died in 1737, at the age of fifty years; and a chart of the course of the river Clyde which he left was published a few years afterwards by his younger brother James. This James Watt, the father of the great engineer, had settled in his native town of Greenock, exercising his abilities, not in the special occupation to which his father and elder brother had devoted themselves, but in the more general sphere of a merchant and public-spirited citizen. During a quarter of a century he held the offices of town-councillor and magistrate of Greenock; and in the discharge of these offices he was noted for his activity and zeal for improvement. It was only in consequence of his own refusal that he did not fill the chair of provost, or chief-magistrate, in Greenock. His special occupations were those of a block-maker and ship-chandler; but, in addition to these, he engaged in house and ship building and general trading. The failure of some of his commercial speculations deprived him, long before his death, of a great part of the fortune which he had acquired. He died in 1782, at the age of eighty-four, having for some years lived retired from business. His wife, Agnes Muirhead, the mother of the illustrious Watt, was of a very respectable family; of her disposition, and the character of her mind, we have no particular account.

The subject of our memoir was the elder of two sons, the only children of the Greenock merchant and his wife. The younger, who was named John, had resolved to follow his father's profession, but

was drowned in 1763 on a voyage from Greenock to America, at the age of twenty-three years. James Watt, who was then in his twenty-seventh year, was thus left the only surviving son.

WATT'S CHILDHOOD AND EDUCATION—SETTLES IN GLASGOW AS A MATHEMATICAL INSTRUMENT MAKER.

Regarding Watt's childhood and the course of his early education, we have not much information. From the extreme delicacy of his health when a child, he was able to attend the public school at Greenock only irregularly and at intervals; so that much of his elementary instruction was received at home. His mother taught him reading, and his father writing and arithmetic; and in his confinement to the house, of which his almost constant indisposition was the cause, he acquired those habits of inquisitiveness and precocious reflection so often observed in feeble-bodied children. "A gentleman one day calling upon his father, observed the child bending over a marble hearth with a piece of colored chalk in his hand. 'Mr. Watt,' said he, 'you ought to send that boy to school, and not allow him to trifle away his time at home.' 'Look how my child is employed before you condemn him,' replied the father. The gentleman then observed that the child had drawn mathematical lines and circles on the hearth. He put various questions to the boy, and was astonished and gratified with the mixture of intelligence, quickness, and simplicity displayed in his answers: he was then trying to solve a problem in geometry." * In this way, not by means of regular lessons, but by incessant employment on some subject of interest or other, Watt in early years acquired much of that general information for which he was in after-life remarkable. His father having, as a means of amusement, presented him with a number of tools such as are used in cabinet-work, he became exceedingly expert in handling them, and began to exhibit his mechanical taste in the fabrication of numerous toys, among which is mentioned a small electrical machine, with a bottle, probably for a cylinder.

An anecdote related of him when he was about fourteen years of age, indicates the extreme restlessness and activity of his mind as a boy. Once having accompanied his mother on a visit to a friend in Glasgow, he was left behind on her return. The next time, however,

*Arago's *Life of Watt.*

that Mrs. Watt came to Glasgow, her friend said to her: "You must take your son James home; I cannot stand the degree of excitement he keeps me in; I am worn out for want of sleep. Every evening before ten o'clock, our usual hour of retiring to rest, he contrives to engage me in conversation, then begins some striking tale, and, whether humorous or pathetic, the interest is so overpowering, that the family all listen to him with breathless attention, and hour after hour strikes unheeded." This wonderful faculty of story-telling, which robbed the Glasgow lady of her sleep, Watt preserved throughout his life to a degree unparaleled perhaps except in Sir Walter Scott.

As he advanced into youth, Watt began to occupy himself with the sciences. The whole range of physics had attractions for him. In excursions in all directions from Greenock, and especially to the banks of Loch Lomond, he studied botany, entered eagerly into the geological speculations then beginning to awaken interest, and collected traditions and ballads—all with equal enthusiasm. At home, during his hours of less robust health, he devoured books on chemistry and general science, among which was Gravesande's *Elements of Natural Philosophy.* Medicine, surgery and anatomy obtained their share of his attention; the detailed descriptions of diseases given in medical works were familiar to him; and he was one day detected carrying into his room the head of a child recently dead, which he had managed somehow to procure, with the intention of dissecting it. In short, by incessant reading and mental activity, he had, before he entered on his nineteenth year, acquired and digested a vast mass of miscellaneous scientific information.

Whether from the prevailing bend of his genius towards mechanical contrivance, or from some other cause connected with the nature of his father's trade in Greenock, the profession which Watt chose was that of a mathematical and nautical instrument maker. To learn this art, or rather to perfect himself in it, he went to London in 1755, and placed himself under Mr. John Morgan, an instrument-maker in Finch Lane, Cornhill. Thus, says M. Arago, "the man who was about to cover England with engines, in comparison with which the antique and colossal machine of Marly is but a pigmy, commenced his career by constructing with his own hands instruments which were fine, delicate, and fragile—those small but admirable reflecting sextants to which navigation is so much in-

debted for its progress." After a residence of little more than a year in London, his continued feeble health obliged him to return to Scotland, where, in accordance with his own wishes and the advice of his friends, he commenced business as a mathematical instrument maker in Glasgow. The date of his settlement in this city, where he was afterwards to work out some of his greatest triumphs, was 1757, when he had just passed his twenty-first year. At first he experienced considerable opposition, and a great deal of annoyance—one of the privileged corporations of the town regarding him as an intruder, and not entitled to practice the business which he professed, at that time a comparatively rare one in Scotland. Various means were tried to soothe down the offended parties, but without effect; they would not even allow the young tradesman to set up a workshop on the smallest scale. At length, apparently through the exertions of the friends of his family, he was rescued from the dilemma by the authorities of the university, who gave him a convenient room within their precincts, and conferred on him the designation of Mathematical Instrument Maker to the College of Glasgow, a proceeding which was sufficient to quash all corporation enmity. In the workshop thus afforded him, Watt continued for a number of years to pursue his trade of making sextants, compasses, etc., for which articles he found customers both within and without the walls of the university. "There are still in existence," says M. Arago, "some small instruments which were at this time made entirely by Watt's own hand, and they are of very exquisite workmanship. I may add that his son has lately shown me some of his first designs, and that they are truly remarkable for the delicacy and precision of the drawing. It was not without reason that Watt used to speak with complacency of his manual dexterity." This, as we have seen, was a gift which seemed to be hereditary in the family.

At the time when Mr. Watt took up his residence in Glasgow, there was a cluster of eminent men gathered together within the university such as is rarely to be found. Adam Smith was Professor of Moral Philosophy; Robert Simson of Mathematics; the illustrious Black filled the chair of Chemistry; and Mr. Dick, who, though less known to fame, is said to have been a man of great powers, held the professorship of Natural Philosophy. Robison, afterwards so celebrated for his attainments in physical science,

which he displayed as a professor both in Edinburgh and Glasgow, was then a student. Watt's position within the college brought him into contact with all these able men; and the shop of the young mathematical instrument maker soon became a lounging-place for both professors and students—the former of whom found in him a man equal to themselves in acquirements, and of a remarkable originality of mind; the latter, a good-natured and willing assistant in their speculations and researches in physics. "I had always," says Professor Robison, referring to those days when he first became acquainted with Watt, "a great relish for the natural sciences, and particularly for mathematical and mechanical philosophy. When I was introduced by Drs. Simson, Dick, and Moor to Mr. Watt, I saw a workman, and expected no more; but was surprised to find a philosopher, as young as myself, and always ready to instruct me. I had the vanity to think myself a pretty good proficient in my favorite study, and was rather mortified at finding Watt so much my superior. Whenever any puzzle came in the way of us students, we went to Mr. Watt. He needed only to be prompted; for everything became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy or made something of it. He learned the German language in order to peruse Leopold's *Theatrum Machinarum*. So did I, to know what he was about. Similar reasons made us both learn the Italian language. When to his superiority of knowledge is added the *naïve* simplicity and candor of Mr. Watt's character, it is no wonder that the attachment of his acquaintances was strong. I have seen something of the world, and I am obliged to say I never saw such another instance of general and cordial attachment to a person whom all acknowledged to be their superior. But that superiority was concealed under the most amiable candor, and a liberal allowance of merit to every man. Mr. Watt was the first to ascribe to the ingenuity of a friend things which were nothing but his own surmises, followed out and embodied by another. I am the more entitled to say this, as I have often experienced it in my own case."

This and similar accounts enable us to figure Mr. Watt during his early residence in Glasgow—a young, amiable, and ingenious man, a great favorite with professors and students, occupied during the greater part of the day in his workshop, but constantly engaged in

the evening in some profound or curious question in mathematics or physical science; quite aware of all that was going on in the scientific world, and taking an interest in all new discoveries, particularly those of his friend Dr. Black in chemistry. As a remarkable instance of the extent of his theoretical research, and of his perseverance in whatever undertaking struck his fancy, it is mentioned that although he had no ear for music, and could never, all his life, distinguish one note from another, or derive pleasure from any musical performance, he astonished all his friends by constructing an organ, which, besides exhibiting numerous ingenious mechanical improvements, was particularly admired by musicians for its greatly superior powers of harmony. His only guide in this difficult achievement must have been the *Harmonies* of Dr. Smith, of Cambridge, a work treating of some of the extreme problems of acoustics, but so profound and obscure, that few persons in the kingdom could have understood a page of it.

In the year 1763, Mr. Watt married his cousin, Miss Miller, who is described as a person of much wit and accomplishment, with great sweetness of temper. At the same time he removed from his apartments in the college to a house in town, in which he continued his profession, enlarging it, however, so as to include engineering. He accordingly began to be consulted in the construction of canals, bridges, and other works of large dimensions requiring science and skill. In the midst of these engineering avocations, a circumstance occurred which exercised a more important influence upon his career than any of them. In the winter of 1763–64, Mr. Anderson, who had succeeded Dr. Dick as Professor of Natural Philosophy, and who is still remembered as the founder of the Andersonian University, Glasgow, finding that a small model of Newcomen's steam-engine, which he had among his apparatus, would not work, sent it to Mr. Watt for repair. The subject of steam-machinery had several times before come under Mr. Watt's notice. His friend Mr. Robison had, in 1759, broached to him the idea of applying steam-power to wheel-carriages; and in 1761–62, he had occupied himself with various experiments on a Papin's Digester, with a view to measure the force of steam. These discussions and experiments, however, terminated in no particular result; and it was Professor Anderson's model of Newcomen's engine that begot in Watt's mind the germ of those ideas respecting the use of steam-power which

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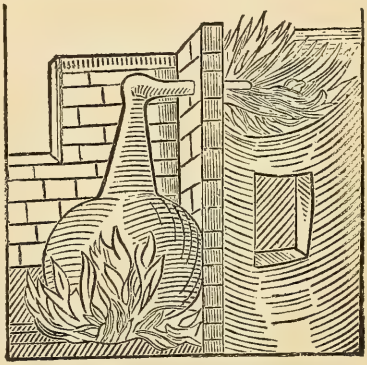
have led to such gigantic consequences. As Newcomen's engine represents the point of progress to which steam-machinery had been brought before Watt applied himself to the subject, this seems the proper place for introducing a sketch of the history of steam-power up to that period. The little black model on the instrument-maker's table was the condensed epitome, as it were, of all that the world knew of steam-power before that time; in the brain of the young newly-married instrument-maker, bending by candlelight over the model, lay, as yet undeveloped, all that the steam-engine has since become.

HISTORY OF THE STEAM-ENGINE BEFORE THE TIME OF WATT.

Steam, or, as they called it, "water transformed into air by the action of fire," was of course known to the ancients, and was used for various ordinary purposes in the arts. The first description, however, of the application of steam as a mechanical power occurs in the writings of Hero, a Greek of Alexandria, who lived in the third century before Christ. This writer, whose attainments in science were very great for his age, describes a toy called the Æolipile, the purpose of which is to produce a rotatory motion by the action of steam. The best familiar illustration of the appearance of such an apparatus, in one of its simplest forms, would be one of those turnstiles, with four horizontal spokes, which are sometimes placed in by-paths. Were one of these revolving stiles made of iron, and hollow throughout, with a hole in the corresponding side of each of the spokes, and were the upright shaft to be fixed into a socket beneath, entering a boiler, then the steam rushing up the shaft and along the four spokes would hiss out in four jets at the side openings, and the whole would, owing to the force of reaction, whirl round in the opposite direction.

Here, therefore, nearly two thousand years ago, we find steam applied to produce a rotatory motion. By connecting the simple rotatory apparatus above described with additional machinery, mills could be driven, and other important mechanical effects produced. Indeed, the construction of rotatory steam-engines has, in recent times, occupied much attention; and, under the name of Barker's Mill, the principle of the Æolipile has been turned to account—the reaction caused by the escape of steam having been made in some instances to do the work of six or eight, or even fifteen horses.

The principle of the Æolipile, however, and of the rotatory engines which are modifications of it, is evidently different from that of steam-engines usually so called, in which the power consists not in the mere reaction caused by steam violently escaping into the atmosphere, but in the prodigious expansive force of steam itself. Water, when converted into steam by the application of heat under the ordinary pressure of the atmosphere, occupies, it is well known, 1728 times its original bulk; in other words, a cubic inch of water is, on its conversion into steam, expanded so as to fill a space of a cubic foot. This is nearly eight times as great as the expansive force of gunpowder. Now, if by any means we could catch water in the act, as it were, of passing into steam, so as to obtain the use of the enormous expansive force for our own purposes, it is evident that we could produce most powerful effects by it. To do this—to catch water in the act of passing into steam, and turn the expansive force to account—is the purpose of steam-engines properly so called.



THE ÆOLIPILE OF HERO OF ALEXANDRIA, B. C. 130.

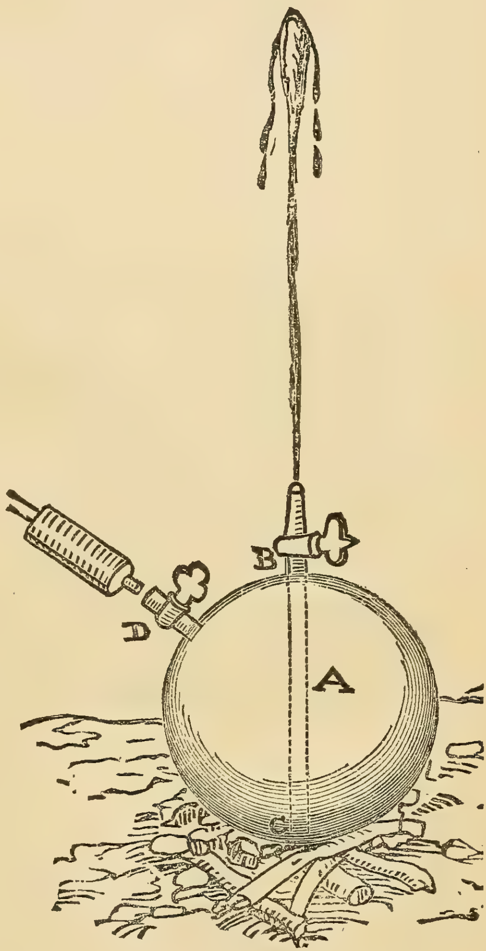
Even this use of the expansive force of steam was in some degree known to the ancients. Often, as M. Arago observes, in casting the fine metal statues for which ancient art is so famous, a drop of water or other liquid would be left enclosed in the plaster or clay moulds when the molten metal was poured in; and the consequence would be an explosion, and, in many cases, a fearful accident, from the instantaneous conversion of the enclosed drop of liquid into steam. Arguing from such instances, the ancient naturalists accounted for earthquakes and submarine explosions on a similar principle, by supposing the sudden vaporization of a mass of water by volcanic heat. Nor were the ancients afraid of handling the power which they thus recognized. In the images of the ancient gods were concealed crevices containing water with the means of heating it; and tubes proceeding from these crevices conducted the steam, so as to make it blow out plugs from the mouths and foreheads of the images with loud noise and apparent clouds of smoke. A more ingenious

device still, and which represents the utmost extent to which the ancients carried their use of the expansive force of steam, is one described by Hero, the purpose of which seems likewise to have been priestly imposition. To accomplish this trick, Hero directs vessels half full of wine to be concealed inside of two figures, in the shape of men standing on each side of an altar. From these vessels, tubes, in the form of bent siphons, with the short end in the wine, proceed along the extended arms of the figures to the tips of their fingers, which are held over the flame of the sacrifice. Other tubes proceed from the same vessels downwards, through the feet of the figures, communicating through the floor with the altar and the fire. "When, therefore," says Hero, "you are about to sacrifice, you must pour into the tubes a few drops, lest they should be injured by heat, and attend to every joint, lest it leak; and so the heat of the fire, mingling with the water, will pass in an aërial state through these tubes to the vases inside the figures, and, pressing on the wine, make it to pass through the bent siphons, until, as it flows from the hands of the living creatures, they will appear to sacrifice as the altar continues to burn." Here we have the expansive force of steam employed directly to raise a liquid, by pressure, above its natural height.

From the time of Hero down to the beginning of the sixteenth century no advance appears to have been made in the application of steam-power. It would appear that as early as 1543 a Spanish captain named Blaxo de Garay showed a steamboat in the harbor of Barcelona of his own invention: it is said that this was on the principle of the Æolipile. Solomon de Caus, a Frenchman of Normandy, who, after a residence in England, where he was employed in designing grottos, fountains, etc., for the palace of the Prince of Wales, afterwards Charles I., at Richmond, returned to the continent, and published an account of these and other inventions at Frankfort in the year 1615. De Caus's steam invention is a modification, in a more patent and distinct form, of the last-mentioned artifice of Hero. A hollow copper globe is filled to the extent of two-thirds or thereby with water, through a funnel-shaped pipe, which enters it, and which is furnished with a stop-cock. Besides this pipe, another descends nearly to the bottom of the globe, so as to have its termination beneath the water. It is likewise furnished with a stop-cock, and its nozzle is

small. If now the vessel be placed over a fire, with the stop-cock of the first pipe shut, and that of the other open, it is evident that when the water begins to boil, the steam being enclosed, will press down the water, and compel it to rush up the second pipe, forming a jet.

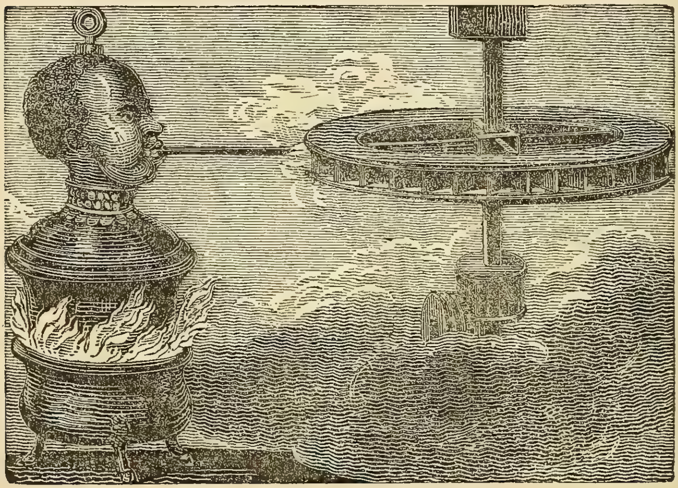
Such is the steam toy of De Caus, upon which many French writers have founded the claim that steam should be considered a French invention. If, however, the merit of a man, with regard to an invention with the origin of which he is concerned, is to be measured by his own perception of its importance, the merit of Solomon de Caus, with regard to steam-machinery, cannot be compared with that of the Marquis of Worcester (known in political history as the Earl of Glamorgan), who, in his *Century of Inventions*, published in 1663, describes "an admirable and most forcible way to drive up water by fire, not by drawing or sucking it upward," but by a method according to which "one vessel of water rarefied by fire driveth up forty vessels of cold water." What value the marquis attached to this invention appears from the striking language he uses with regard to other modifications of it. Of one he



DE CAUS, A. D. 1615.

says: "I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me." He also describes a water-work capable, he says, of raising water with the utmost facility to the height of a hundred feet, and which will, therefore, "drain all sorts of mines, and furnish cities with water though never so high seated." This he pronounces "the most stupendous work in the whole world—an invention which crowns his labors, rewards his expenses, and makes his thoughts acquiesce in the way of further inventions."

In 1629 Giovanni Branca, an Italian machinist, invented and pub-



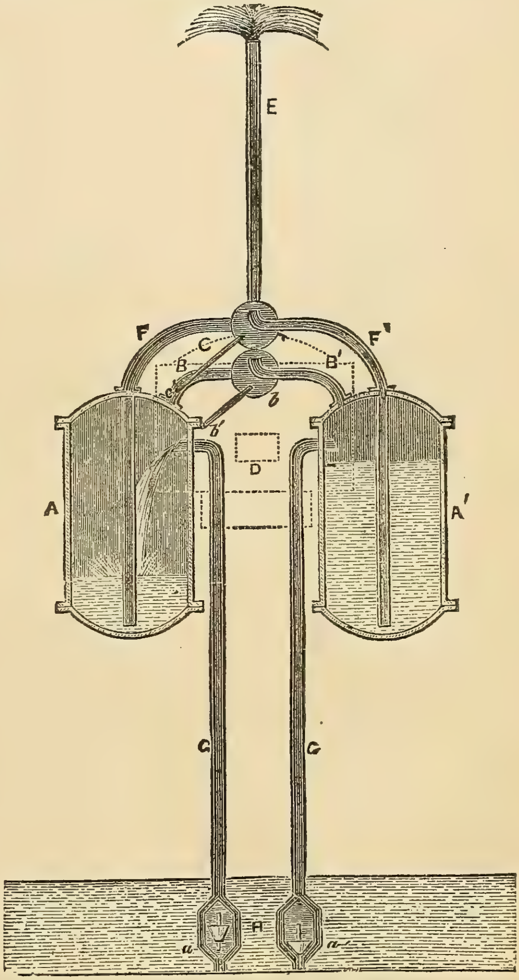
GIOVANNI BRANCA, 1629.

lished a highly suggestive contribution to steam discovery. This represents the operation of pounding, the pestles being acted on by pulleys and cog-wheels, set in motion by a jet of steam issuing from a pipe against the vane of a horizontal wheel. This was the first practical steam-engine.

It is ascertained that the Marquis of Worcester had actually constructed a steam model apparatus. Although, however, it would thus seem that steam-power, in one of its most imposing forms, was in actual operation so early as 1656, the invention does not appear to have taken root; and it is not till 1699, upwards of thirty years after the Marquis of Worcester's death, that we find the steam-

engine again pressed on public notice. In that year Captain Thomas Savary exhibited to the Royal Society a model of an engine for draining mines, and raising water to great heights. The difference between the Marquis of Worcester's invention and Savary's consisted in this, that whereas "the marquis's model appears to have been placed on or below the level of the water to be raised, so that the water was forced up solely by the elastic force of the steam, Savary, on the other hand, erected his engine at a height of nearly thirty feet above the level of the water."

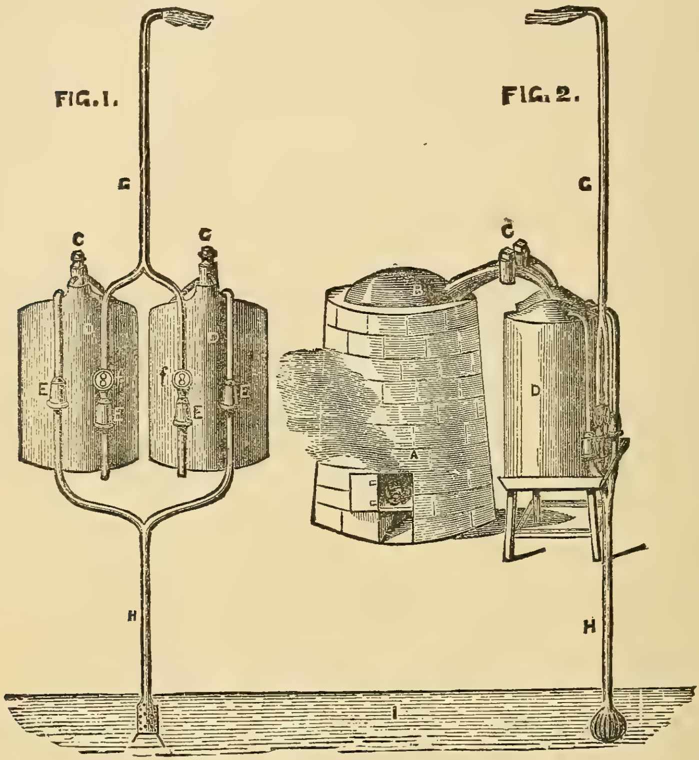
The improvement of Savary consists in combining the force of atmospheric *suction*, as it is usually called, with that of steam-pressure; using the first to raise the water thirty feet, and then the other to raise it thirty feet or more additional; and when it is considered that, in the actual working engine, there was not only one receiver, but two, which could be



THE MARQUIS OF WORCESTER ENGINE, 1663.*

* The Marquis of Worcester's "Water Commanding Engine" was patented in 1663, but the inventor was engaged on the mechanical arrangements of it as early as 1647.

alternately filled with steam and cooled, so as to prevent the loss of time, the value of the improvement will be seen to be very great.



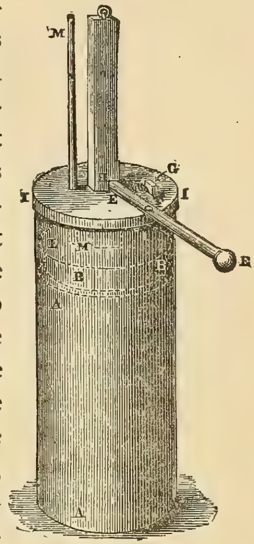
SAVARY'S ENGINE, 1699.*

Savary called his machine the "Miner's Friend;" it seems, however, to have been used only for the purpose of raising water in houses.

On page xvii is a drawing of this engine. A, A^1 are two cold water vessels connected by B, B^1—the steam pipe—with C, the boiler, set in D, the furnace. The cold water vessels A, A^1, also are connected with E, the vertical water pipe, by means of F, F, continuations of the same pipe conducted into and nearly touching the bottom of each vessel A, A^1. G, G^1 are two water supply pipes with valves, a, a^1, dipping into H, the well. It is obvious that by uniting these pipes and placing the valves in the upper bend of each, it would be sufficient for a single pipe to dip into the water to be raised. On the steam pipe B, B^1 is b, a four-way steam cock, operated by b^1, its lever handle; and on the horizontal portion of the water pipe F, F^1 is c, a four way water cock operated by c^1, its lever handle.

* In the 21st volume of *Philosophical Transactions*, published in 1700, there is a de-

The next great contribution to the steam-engine came from a French engineer, Denis Papin, known for other important mechanical inventions. His important service to steam-power consisted in the idea of making it act through *the cylinder and piston.* In De Caus's and Savary's apparatus the steam pressed directly upon the surface of the water; but Papin conceived the idea of introducing the steam into the bottom of the receiver, so as to force up, by its elasticity, a tightly-fitting plate or piston, which would again descend by the pressure of the atmosphere as soon as the steam beneath was condensed. The importance of this modification can hardly be overrated, when it is considered that it amounts to the application of steam-power to produce the motion of a rod up and down in a cylinder. This was the great step, the conciliation of steam, as it were, into a regular moving power at the command of man; and, as M. Arago observes, the procuring afterwards, from the strokes of the piston, the power



PAPIN'S STEAM AND AIR ENGINE, MAY, 1689.*

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scription, with an engraving, being "An account of Mr. Thomas Savery's engine for raising water by the help of fire." The engine may be understood by the double diagram, see page xviii. The drawing on the left is the front of the engine; that on the right is a side view. A, is the furnace; B, the boiler; C, two cocks which convey the steam from the bottom in order to discharge it again at the top; D, the vessels which receive the water from the bottom in order to discharge it again at the top; E, valves; F, cocks which keep up the water, while the valves on occasion are cleaned; G, the force pipe; H, the sucking pipe; and I, the water.

* AA is a tube of uniform diameter throughout, close shut at the bottom; BB is a piston fitted to the tube; DD, a handle fixed to the piston; EE, an iron rod movable round an axis F; G, a spring pressing the cross-rod EE, so that the said rod must be forced into the groove H, as soon as the piston with the handle has arrived at such a height as that the said groove H appears above the lid II; L is a little hole in the piston, through which the air can escape from the bottom of the tube AA, when first the piston is forced into it. The use of this instrument is as follows:—A small quantity of water is poured into the tube AA, to the depth of three or four lines; then the piston is inserted and forced down to the bottom, till a portion of the water previously poured in comes through the hole L; then the said hole is closed by the rod MM. Next the lid II, pierced with the apertures requisite for that purpose, is put on, and a moderate fire being applied, the tube AA soon grows warm (being made of thin metal), and the

to turn millstones, or the paddles of a steamboat, or to uplift the massy hammer, or to move the huge clipping shears—these were but secondary problems. Papin, however, did not work out his own conception—did not perceive all its consequences.

The next modification of the steam-engine, and its ultimate one before it came into the hands of Watt, consisted, it may be said, in the union of Savary's idea with that of Papin. The authors of this invention—which may in reality be considered as the first working steam-engine—were Thomas Newcomen, an ironmonger, and John Cawley, a glazier, both of Dartmouth, in Devonshire. In the year 1705 these two individuals "constructed a machine which was meant to raise water from great depths, and in which there was a distinct vessel where the steam was generated. This machine, like the small model of Papin, consisted of a vertical metallic cylinder, shut at the bottom and open at the top, together with a piston accurately fitted, and intended to traverse the whole length, both in ascending and descending. In the latter, as in the former apparatus also, when the steam was admitted into the lower part of the cylinder, so as to fill it, and counterbalance the external atmospheric pressure, the ascending movement of the piston was effected by means of a counterpoise. Finally, in the English machine, in imitation of Papin's, as soon as the piston reached the limit of its ascending stroke, the steam which had impelled it was refrigerated; a vacuum was thus produced, and the external atmosphere forced the piston to descend."* The only novelty in Newcomen's engine, over and above what had existed either in Papin's or in Savary's model, was the mode of condensing the steam in the cylinder. This was effected not by simply withdrawing the heat from the bottom of the cylinder, as Papin had done, nor by dashing cold water on the outside of it, as in Savary's apparatus, but in directing a stream of cold water

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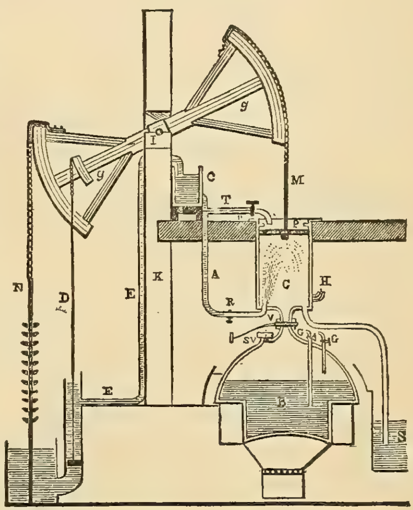
water within it being turned into steam, exerts a pressure so powerful as to overcome the weight of the atmosphere and force up the piston BB, till the grove H, of the handle DD, appears above the lid II, and the rod EE is forced, with some noise, into the said groove by the spring G. Then forthwith the fire is to be removed, and the steam in the thin metal tube is soon resolved into water, and leaves the tube entirely void of air. Next the rod EE, being turned round so far as to come out of the groove H, and allow the handle D to descend, the piston BB is forthwith pressed down by the whole weight of the atmosphere, and causes the intended movement; which is of an energy great in proportion to the size of the tube.

* Arago's *Life of Watt.*

into the inside of the cylinder at every rise of the piston. This improvement—an important one at the time—is said to have been made by accident, from the circumstance of water once finding its way into the cylinder through a hole in the piston, and astonishing the onlookers by its results. The entire action of Newcomen's engine will be understood from the annexed cut, representing a section of it. B is the boiler, built over a furnace, and kept about two-thirds full of water; the quantity of water being regulated by means of two vertical tubes with stop-cocks (GG), which descend into the boiler, the one to a greater depth than the other, so that when the boiler contains its proper quantity of water, the longer tube shall dip into it, while the shorter does not reach it. When the boiler is heated, the pressure of the steam in its upper part will, if the proper quantity of water be in the boiler, force the water up the longer pipe, while only steam issues from the shorter. Should both pipes emit water, then it is known that the boiler is too full; should both emit steam, that it is not full enough; and the supply can be regulated accordingly. Besides these *gauge-pipes* there is in the boiler a *safety-valve* (SV), loaded so as to lie tight until the steam in the boiler accumulates to a degree sufficient to force it up. From the boiler the steam passes through the connecting tube, guarded by the *regulating-valve* (V), made so as to open and shut easily, into the cylinder (C). Up and down in this cylinder, which is open at the top, moves the piston (P), attached by means of the piston-rod (M) to a flexible chain, which is fastened to the top of the arch at the end of a beam, moving on the pivot (I). The end of the beam to which the piston-rod is attached is made lighter than the other end, so that when the engine is at rest, it ascends and pulls up the piston to the top of the cylinder. The



NEWCOMEN'S ENGINE, 1705.

piston thus lying at the top of the cylinder, lets the steam from the boiler be admitted through the regulating-valve (V). The steam rushing in expels the air which was in the cylinder through the *snifting-valve* (H), which is at the bottom of the cylinder, and so constructed, that although it permits the escape of the air, it allows none to enter. The whole space of the cylinder underneath the piston being now filled with steam, the next operation is to condense it. This is done by turning a cock (R) in the tube (A), which descends from a cistern kept constantly full of cold water. The water, tending to rise to the height from which it has fallen, spouts into the cylinder, striking against the bottom of the piston, and falling down in a shower of drops, which cool the cylinder and condense the steam. This condensation of the steam produces a vacuum in the cylinder; and the piston, pressed down by the weight of the atmosphere outside, rapidly descends—the water which was thrown into the cylinder being carried off by the long *eduction-pipe* which, having a valve at its extremity opening only outwards, leads to a cistern (S), whence the boiler is supplied. The descent of the piston pulls down the piston-rod and chain, and the end of the beam to which they are attached. The other end of the beam accordingly rises, pulling up a chain which is attached to the *pump-rod* (N), working the pump by which the mine is to be drained. The purpose of the smaller *pump-rod* working parallel to N, is, by the action of the engine, to raise a portion of the water through the tube (EE) to the cistern from which the water is sent into the cylinder. The piston is now at the bottom of the cylinder, and would remain there by the pressure of the atmosphere on its upper surface; but by opening the valve (V), the steam from the boiler is admitted under it, and the pressure of the atmosphere being thus counterbalanced, the superior weight of the pump-rod end of the beam causes it to descend, elevating the other end with the piston attached to it. The cylinder being again filled with steam as before, the stop-cock (R) is turned, and the water spouts in; the steam is condensed; the piston descends; the pump-rod rises; and so on, stroke after stroke. The use of the small tube (T), proceeding from the cistern, is to pour a little water above the piston, to keep it air-tight.

As may be supposed, much care and attention was at first required in Newcomen's engine on the part of the person whose work it was

to keep incessantly turning the stopcocks (V and R); the first for the admission of steam from the boiler, the second for the admission of the cold water for the condensation of the steam. The whole action of the machine depended on the attention of the person who watched these two cocks. A curious accident, however, remedied this inconvenience. A boy of the name of Humphrey Potter being employed to tend one of Newcomen's engines, found the constant watching so troublesome that he set himself to contrive a way by which the cocks might be turned at the right time, and yet he might enjoy himself for an hour or so at a time with the boys in the street. Observing that the particular moment at which the valve (V) required to be opened for the admission of the steam was that at which the pump-rod end of the beam was raised to its highest and that the moment at which the other cock (R) required to be opened was when the piston-rod end was at its highest, he saw that, by attaching strings to the stop-cocks, and connecting them with various parts of the beam, the rising and falling of the two ends would turn the cocks regularly as was necessary. Such was the *scogging* or *skulking gear* of the boy Potter, so called because it enabled him to *scog* or play truant from his work, and afterwards improved by the substitution of rods for strings. The steam-engine was now entirely self-working; the only attendant necessary was the fireman to tend the furnace.

Such was the atmospheric engine of Newcomen, used to a considerable extent for the purpose of draining mines, and upon which various engineers employed their skill during the first half of the eighteenth century, with a view to render it applicable to other mechanical purposes, such as driving mills, etc. Among those who thus directed their attention to the steam-engine was the celebrated Smeaton; and some of the finest specimens of Newcomen's engine were of his construction. No improvement of essential consequence, however, was effected in the steam-engine until it came into the hands of Watt, whose successive contrivances to render it perfect we now proceed to describe.

WATT'S IMPROVEMENTS ON THE STEAM-ENGINE AS A DRAINING AND PUMPING MACHINE.

Watt was a man with whom, to repeat the words of Professor Robinson, "everything became the beginning of a new and serious

study;" accordingly, not content with merely repairing Professor Anderson's model, so that it should work as before in presence of the students in the class-room, he devoted himself to the thorough investigation of all parts of the machine and of the theory of its action. Directing his attention first, with all his profound physical and mathematical knowledge, to the various theoretical points involved in the working of the machine, "he determined," says M. Arago, "the extent to which the water dilated in passing from its liquid state into that of steam. He calculated the quantity of water which a given weight of coal could vaporize—the quantity of steam, in weight, which each stroke of one of Newcomen's machines of known dimensions expended—the quantity of cold water which required to be injected into the cylinder to give the descending stroke of the piston a certain force—and, finally, the elasticity of steam at different temperatures. All these investigations would have occupied the lifetime of a laborious philosopher; whilst Watt brought all his numerous and difficult researches to a conclusion, without allowing them to interfere with the labors of his workshop."

Leaving Watt's theoretical researches into the mode and power of action by steam, let us attend to the practical improvements which he made in the construction of the engine itself. Newcomen's machine labored under very great defects. In the first place, the jet of cold water into the cylinder was a very imperfect means of condensing the steam. The cylinder, heated before, not being thoroughly cooled by it, a quantity of steam remained uncondensed, and, by its elasticity, impeded the descent of the piston, lessening the power of the stroke. Again, when the steam rushed into the cylinder from the boiler, it found the cylinder cold in consequence of the water which had recently been thrown in, and thus a considerable quantity of steam was immediately condensed and wasted, while the rest did not attain its full elasticity till the cylinder became again heated up to 212 degrees. These two defects—the imperfection of the vacuum created in the cylinder when hot and the loss of steam in rushing into the cylinder when cold—were sources of great expense. Both defects, it will be observed, had their origin in the alternate heating and cooling of the cylinder; and yet, according to Newcomen's plan, this alternate heating and cooling was inevitable.

Watt remedied the evil by a simple but beautiful contrivance—his SEPARATE CONDENSER. The whole efficacy of this contrivance consisted in his making the condensation of the steam take place, not in the cylinder, but in a separate vessel communicating with the cylinder by a tube provided with a stop-cock. This vessel being exhausted of air, it is evident that, on the turning of the stop-cock in the tube connecting it with the cylinder, the steam from the cylinder will rush into it so as to fill the vacuum; and that this will continue until the steam be equally distributed through both vessels—the cylinder and the other. But if, in addition to being free from air, the separate vessel be kept constantly cool by an injection of cold water, or other means, so as to condense the steam as fast as it rushes in from the cylinder, it is evident that *all* the steam will quit the cylinder, and enter the separate vessel, to be condensed there. The cylinder will be thus left a perfect vacuum, without having lost any of its heat by the process; the piston will descend with full force, and when the new steam rushes in from the boiler no portion of it will be wasted in reheating the cylinder.

So far the invention was all that could be desired; an additional contrivance was necessary, however, to render it complete. The steam in the act of being condensed in the separate vessel would give out its latent heat; this would raise the temperature of the condensing water;* from the heated water vapor would rise, and this vapor, in addition to the atmospheric air which would be disengaged from the injected water by the heat, would accumulate in the condenser and spoil its efficiency. In order to overcome this defect, Watt attached to the bottom of the condenser a common air-pump, called the *condenser pump*, worked by a piston attached to the beam, and which, at every stroke of the engine, withdrew the accumulated water, air and vapor. This was a slight tax upon the power of the machine, but the total gain was enormous—equivalent to making one pound of coal do as much work as had been done by five pounds in Newcomen's engine.

This, certainly, was a triumph; but Watt's improvements did not

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*The effect of the latent heat of the steam in heating the water in the condenser may be judged of from the fact that, if *two* pounds of steam be condensed by *ten* pounds of *freezing* water, the result will be twelve pounds of water at the *boiling*-point; in other words, two pounds of steam at 212 degrees contain latent heat sufficient to boil ten pounds of freezing water.

stop here. In the old engine the cylinder was open at the top, and the descent of the piston was caused solely by the pressure of the atmosphere on its upper surface. Hence the name of *Atmospheric* Engine, which was always applied to Newcomen's machine, the real moving power being not the steam, which served no purpose except to produce the necessary vacuum, but the atmosphere pressing on the piston with the force (supposing the vacuum to be complete) of about fifteen pounds to a square inch. This was attended with the inconvenience that, the atmosphere being cold, tended to cool the inside of the cylinder in pushing down the piston, which, of course, caused a waste of steam at every stroke. The inconvenience was avoided, and the whole engine improved, by entirely shutting out the atmospheric action and employing the steam itself to force down the piston. This was accomplished in the following way. Instead of a cylinder open at the top Watt used one with a close metallic cover, with a nicely-fitted hole in it, through which the greased piston-rod could move freely, while it did not allow the passage of air or steam. Thus the cylinder was divided into two chambers quite distinct from each other—that above and that below the piston. Now, in addition to the former communications between the cylinder and the boiler and condenser, a tube was made to connect the boiler with the upper chamber, so as to introduce steam *above* the piston. This steam, by its elastic force, and no longer the atmosphere by its pressure, drove down the piston when the vacuum had been formed by the condensation of the steam beneath; and as soon as the descending stroke was complete, the turning of a cock could admit steam from the boiler equally into both chambers, thus restoring the balance and enabling the piston to ascend, as before, by the mere counterpoise of the beam. The engine with this improvement Watt named the *Modified Engine;* it was, however, properly the first real *steam*-engine; for in it, for the first time, steam, besides serving to produce the vacuum, acted as the moving force. In this substitution of steam as the moving force instead of the atmosphere, there was, moreover, this peculiar advantage—that whereas the force of the atmosphere was uniform, and could in no case exceed fifteen pounds on every square inch of the piston's surface, the force of the steam could, within certain limits, be varied.

Another improvement less striking in appearance, but of value in

economizing the consumption of fuel, was the enclosing of the cylinder in a jacket or external drum of wood, leaving a space between which could be filled with steam. By this means the air was prevented from acting on the outside of the cylinder so as to cool it. A slight modification was also necessary in the mode of keeping the piston air-tight. This had been done in Newcomen's engine by water poured over the piston; but in the closed cylinder this was obviously impossible; the purpose was therefore effected by the use of a preparation of wax, tallow and oil smeared on the piston-rod and round the piston-rim.

The improvements which we have described had all been thoroughly matured by Mr. Watt before the end of 1765, two years after his attention had been called to the subject by the model of Newcomen's engine sent him for repair. During these two years he had been employing all his leisure hours on the congenial work, performing his experiments in a delft manufactory at the Broomielaw quay, where he set up a working model of his engine, embodying all the new improvements and having a cylinder of nine inches diameter. One would anticipate, as M. Arago remarks, that when the fact of the construction of so promising and economical an engine was made generally known, "it would immediately displace, as a draining apparatus, the comparatively ruinously expensive machines of Newcomen. This, however, was far from being the case. Watt's grand invention and most felicitous conception, that steam might be condensed in a vessel quite separated from the cylinder, was completed in the year 1765; and in two years scarcely any progress was made to try its applicability upon the great scale." Watt himself did not possess the necessary funds for that purpose. "At length," says Lord Brougham, "he happily met with Dr. Roebuck, a man of profound scientific knowledge and of daring spirit as a speculator. He had just founded the Carron iron-works, not far from Glasgow, and was lessee, under the Hamilton family, of the Kinneil coal-works." Such a man, so extensively employed in engineering, was precisely the person to introduce Watt's invention into practice; and accordingly a partnership was formed between him and Watt, according to the terms of which he was to receive two-thirds of the profits in return for the outlay of his capital in bringing the new machines into practice. A patent was taken out by the partners in 1769, and an engine of the new construction, with an eighteen-inch

cylinder, was erected at the Kinneil coal-works with every prospect of complete success, when, unfortunately, Dr. Roebuck was obliged by pecuniary embarrassments to dissolve the partnership, leaving Watt with the whole patent, but without the means of rendering it available.

WATT'S OCCUPATIONS AS A GENERAL ENGINEER—HIS PARTNERSHIP WITH MR. BOULTON OF SOHO.

Watt, rather than apply to the money-lenders for funds, which they would very probably have been glad to invest in so hopeful a speculation, devoted himself for some time exclusively to the proper business of his profession as a civil engineer, allowing his steam-engine model to lie like mere lumber in the Broomielaw delft-work. Between the years 1769 and 1774 he was employed in various engineering enterprises of great importance—"the extensive operations of which Scotland then became the scene giving," says Lord Brougham, "ample scope to his talents. He was actively engaged in the surveys and afterwards in the works for connecting by a canal the Monkland coal-mines with Glasgow. He was afterwards employed in preparing the canal, since completed by Mr. Rennie, across the Isthmus of Crinan; in the difficult and laborious investigations for the improvement of the harbors of Ayr, Greenock and Glasgow; in improving the navigation of the Forth and Clyde, and in the Campbelton Canal, besides several bridges of great importance, as those of Hamilton and Rutherglen." * "What Johnson said of Goldsmith may with equal justice be applied to Watt—'he touched nothing that he did not adorn.' In the course of his busy surveys his mind was ever bent on improving the instruments he employed, or in inventing others to facilitate or correct his operations. During the period of which we have been speaking he invented two micrometers, for measuring distances not easily accessible, such as arms of the sea. Five years after the invention of these ingenious instruments one Mr. Green obtained a premium for an invention similar to one of them, from the Society of Arts, notwithstanding the evidence of Smeaton and other proofs that Watt was the original contriver.

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* Memoir of Watt in Lord Brougham's *Men of Letters of the Reign of George III.*

"In 1773 the importance of an inland navigation in the northern part of Scotland between the eastern and western seas became so great that Mr. Watt was employed to make a survey of the Caledonian Canal and to report on the practicability of connecting that remarkable chain of lakes and valleys. These surveys he made and reported so favorably of the practicability of the undertaking that it would have been immediately executed had not the forfeited lands from which the funds were to be derived been restored to their former proprietors. This great national work was afterward executed by Mr. Telford on a more magnificent scale than had been originally intended."

At the end of the year 1773 Watt was left a widower by the death of his wife in Glasgow while he was absent on his survey of the Caledonian Canal. Two children, a son and a daughter, survived their mother. This event would probably have the effect of withdrawing his attention still more from his steam inventions. For five years his patent "for methods of lessening the consumption of steam and consequently of fuel in the steam-engine" had been running without bringing him any returns, the dissolution of his partnership with Dr. Roebuck having thrown the entire risks of introducing the new machine into practice upon himself, and either his cautious temperament or his actual want of means preventing him from abandoning the certainties of his profession for the sake of pushing his steam-engine into public notice. This indifference is certainly in itself not entitled to be considered a merit; we point it out merely as characteristic.

At length, in 1774, Mr. Watt entered into a partnership most fortunate for himself and for the world. This was with Mr. Matthew Boulton, of the Soho Foundry, near Birmingham—a gentleman of remarkable scientific abilities, of liberal disposition and of unbounded enterprise, who, having his attention called to the improvements on Newcomen's steam-engine effected by the Glasgow surveyor, immediately formed a connection with him, sharing the patent, as Dr. Roebuck had formerly done.

Almost the first business of the partners was to procure a prolongation of Watt's patent, which, having commenced in 1769, had but a few years to run. Whether because the value of Watt's improvements had, by the mere course of time, become more generally recognized than at first, or because the enthusiasm with which so

well-known an individual as Mr. Boulton patronized them, roused many parties to a sense of their importance, it was only after a very keen opposition in Parliament that the extension of the patent for twenty-five years was obtained. At the head of those who opposed the renewal of the patent in the House of Commons was the celebrated Edmund Burke; the opponents out of the house were the engineers and miners whom the patent would prevent from employing the engine without paying the inventor for permission to do so.

The extension of the patent having been procured, the partners began to construct, at their manufactory at Soho, draining-machines of the largest dimensions, which immediately supplanted Newcomen's engines in all the mining districts. The bargain which the partners made with those mine proprietors who applied for permission to use the improved engine was certainly the most reasonable that could have been expected. They stipulated for receiving "a third part of the value of the coal saved by the use of the new engine." Yet this agreement brought ample profits to the partners, as may be judged from the fact, that the proprietors of the single mine of Chasewater in Cornwall, where three pumps were employed, commuted the proposed *third of the coal saved* into £2500 a year for each of the engines. Thus the saving effected by one engine amounted to at least £7500, which had been expended formerly in waste fuel. As there was a possibility that, if the mine proprietors had been left to estimate for themselves the value of the saving, they might cheat the partners of their fair dues, Watt rendered himself independent of them by confiding the duty of rendering an account to a meter, invented on purpose, and which, kept in a box under a double lock, registered every stroke of the engine.

As the engine was one of large dimensions, it was scarcely possible to pirate it secretly; but so numerous were the attempts made to plagiarise it, or, by ingenious ways, to infringe the patent right, that Messrs. Watt and Boulton were almost perpetually engaged in lawsuits to defend their property. In several cases, the opposition which Mr. Watt experienced on account of his defending his rights amounted to positive persecution—to attacks on his character. These attacks, however, failed; and in their lawsuits the partners were uniformly successful. "I have been so beset with plagiaries," says Mr. Watt in one of his letters, "that if I had not a very distinct recollection of my doing it, their impudent assertions would lead me

to doubt whether I was the author of any improvement on the steam-engine."

As the foundry at Soho was one of the largest establishments in Great Britain, Watt's new position, as a partner with Mr. Boulton, was one of great wealth and consequence. He had hardly entered upon it, when, in the year 1775, after two years of widowhood, he married Miss Macgregor, the daughter of a rich Glasgow merchant.

The first consequence of the introduction of Watt's improved steam-engine into practice was to give an impulse to mining speculations. New mines were opened; and old mines, which could not be profitably worked when taxed with such a consumption of fuel for draining as Newcomen's engines required, now yielded a return. This was the only obvious consequence at first. Only in mines, and generally for the purpose of pumping water, was the steam-engine yet used; and before it could be rendered applicable to other purposes in the arts—before it could promise, even to the most sanguine expectation, to perform such a universal part in machinery as that which we now witness it performing—the genius of Watt required once again to stoop over it, and bestow on it new creative touches.

IMPROVEMENTS BY WATT, RENDERING THE STEAM-ENGINE APPLICABLE FOR GENERAL PURPOSES.

Any one, on considering the steam-engine, will perceive that the original motion in it, and the source of all others, is that of the piston up and down in the cylinder. It is by connecting the piston-rod with other pieces of machinery through a beam that the work is done. Now, in the draining-engine the piston-rod was attached to the beam by a flexible chain. Where the purpose was the mere pumping of water, the inconvenience of this was not so great; but to render the steam-engine useful for other purposes, it was necessary to do away with the flexible chain, and connect the piston-rod with the end of the beam by some *rigid communication.* Watt effected this by a beautiful invention, known as *the parallel motion.* At the end of the beam of a steam-engine of the construction common some years ago,* may be observed a curious jointed parallelogram,

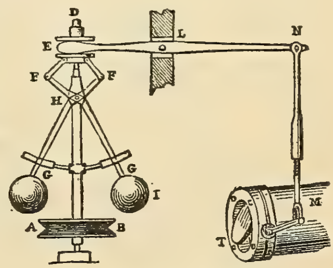
* In engines of modern construction the beam is seldom used; the crank-rod is jointed directly to the piston-rod, and the piston-rod is made to preserve its parallelism by means of a cross-head moving in guides.

with the piston-rod attached to one of its angles. When the engine is in action, if the movements of this parallelogram be watched attentively, it will be perceived that while three of the angles of the parallelogram move in small circular arcs, the fourth—that to which the piston-rod is attached—is so pulled upon by opposite forces, that although tending to move in a curve, it moves in a straight line. This result depends on a very recondite mathematical principle; the contrivance, however, practically, is one of the most simple imaginable. "I myself," says Watt, speaking of his first trial of the parallel motion, "have been much surprised with the regularity of its action. When I saw it in movement, it afforded me all the pleasure of a novelty, and I had quite the feeling as if I had been examining the invention of another."

Another improvement, which, in point of the additional power gained, was more important than the parallel motion, and which indeed preceded it in point of time, was the *Double-acting Engine.* In the steam-engine, so far as we have yet described it, the whole force consisted in the downward stroke; in the depression of the piston in Newcomen's engine by the atmosphere; and in Watt's improved engine by the steam admitted into the upper chamber of the cylinder. When the piston had reached the bottom of the cylinder, it arose again by the mere counterpoise of the other end of the beam, just as the lighter end of a weighing-beam ascends when the pressure which kept it down is removed. Watt remedied this defect, by giving the piston an upward as well as a downward stroke; that is, by employing the steam to push up the piston as well as to push it down. After the whole cylinder is first filled with steam, a communication is opened between the upper chamber and the condenser; thus the steam in the upper chamber is condensed, and a vacuum is formed, upon which the elasticity of the steam in the lower chamber pushes up the piston. This is the ascending stroke. To procure the descending stroke, a communication is next opened between the *lower* chamber of the cylinder and the condenser; by this means a vacuum is formed below the piston; steam is then admitted into the *upper* chamber, and its elasticity pushes the piston down. And thus, by the alternate admission and condensation of steam above and below the cylinder, the double action is procured, giving a double power for the same size of cylinder, and there is no longer any necessity for one end of the beam being heavier than the other.

Besides the double-stroke engine Mr. Watt also indicated an improvement, which he did not fully carry out, but which has since been attended with results so surprising as regards the economizing of the steam that its utility ranks as high as that of the separate condenser. This consists in shutting off the steam from the boiler before the whole length of the stroke, whether upward or downward, is completed, leaving the quantity admitted to perform the rest of the stroke by its expansive force. When the steam is shut off at half-stroke it is found that the efficacy of the steam is increased by considerably more than a half; at quarter-stroke, the same quantity of steam—and, therefore, the same quantity of fuel—will do more than twice the work it would do if steam were admitted during the whole stroke.

Watt had thus gone as far as it was possible to go in increasing the power of the steam-engine. "*Power*, however," observes M. Arago, "is not the only element of success in the labors of industry. *Regularity* of action is of no less importance; and what degree of regularity is to be expected from a moving power which is procured from the fire, under the influence of the poker and shovel, and supplied by coals of very different qualities: under the influence, too, of workmen often far from intelligent and almost always inattentive? We should expect that the propelling steam would be sometimes superabundant; that hence it would rush into the cylinder with greater rapidity, so making the piston work more rapidly according as the fire was more powerful, and from such causes great inequalities of movement appear almost inevitable." Watt's genius provided a remedy for this by an ingenious application of an apparatus called the *governor*, which should regulate the quantity of steam admitted from the boiler into the cylinder. The nature of this piece of mechanism will be understood by the annexed figure. A spindle or upright log, with a pulley on its lower part by which it is moved, receiving motion through a strap attached to the shaft or axle, has two balls, which revolve along with it. These balls, by the means of joints, may be separated considerably from, or brought nearer to,



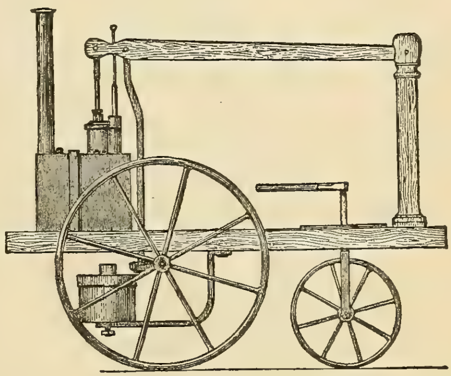
WATT'S GOVERNOR.

the spindle. Two levers are connected with the rods to which the balls are attached, having a free movement on other levers similar in length and thickness, but which meet in a metallic ring movable upwards and downwards on the spindle. Immediately above the ring a lever is placed transversely across the ring, fixed at one point, but connected to another which is bent, to the end of which the throttle-valve of the steam-pipe is attached. This valve, it may be here noticed, is intended to regulate the supply of steam, allowing it to escape when horizontal in full stream and obstructing it proportionately as it assumes a vertical direction. When, therefore, the engine acts with increased speed or velocity, and the main shaft to which this spindle is attached is revolved with a proportionate degree of rapidity, the balls will recede to a greater distance from each other, and accordingly the levers, acting on the throttle valve, will raise it so as to diminish the flow of steam. But if the shaft revolves slowly, the spindle also having its velocity regulated by it, the balls will naturally approximate each other, and the lever will now so act on the valve as to throw it completely open, and thereby permit the steam to enter in a full current to the cylinder and accelerate the motion. Such is the efficacy of this apparatus that by its means a steam-engine may be made to give motion to a clock which shall keep good time. "It is this regulator of Watt's," says M. Arago, "and a skilful employment of fly-wheels, which constitute the true secret of the astonishing perfection of the manufactures of our epoch. It is this which confers on the steam-engine a working movement which is wholly free from irregularity and by which it can weave the most delicate fabrics as well as communicate a rapid movement to the ponderous stones of a flour-mill."

To describe all the other inventions of a minor kind connected with the steam-engine which came from the prolific genius of Watt would occupy too much space. Rotary engines, already alluded to in the present History, and which have engaged much attention of late years, were not only thought of by Watt, but actually constructed; "he subsequently abandoned them, however, not because they did not work, but because they appeared to him decidedly inferior, in an economical point of view, to machines of double powers and rectilineal oscillations." The earliest results of his improvements in the application of steam will be found in Cugnot's (French) "Road Steam Engine," 1770, page xlviii; and about ten years later,

in 1784, William Symington, one of the early inventors of the steamboat, was similarly occupied in Scotland in endeavoring to perfect the steam carriage; but, chiefly because of the bad roads in Scotland at that period, he had to abandon it.

The same year William Murdock, the friend and assistant of Watt, constructed his model of a locomotive at Redruth, in Cornwall. It was of small dimensions, standing little more than a foot high; and it was until recently in the possession of the son of the inventor. The annexed section will give an idea of the arrangements of this machine.



MURDOCK'S MODEL OF A LOCOMOTIVE ENGINE, 1784.

It acted on the high-pressure principle, the boiler being heated by a spirit lamp. Small though the machine was, it went so fast on one occasion that it fairly outran the speed of the inventor. It was a dark night, and Murdock set out alone to try his experiment. Having lit his lamp, the water shortly began to boil, and off started the engine with the inventor after it. He soon heard distant shouts of despair. It was too dark to perceive objects; but he shortly found, on following up the machine, that the cries proceeded from the worthy pastor of the parish, who, going towards the town on business, was met on this lonely road by the hissing and fiery little monster, which he subsequently declared he had taken to be the Evil One *in propria persona*. No further steps, however, were taken by Murdock to embody his idea of a locomotive carriage in a more practical form.

To express by any ordinary terms in our language the advantages resulting from Watt's improvements of the steam-engine would be altogether impossible. We have only to look abroad on the world and see what mighty applications of this wonderful engine are everywhere visible. Steam navigation, railway travelling, automatic factory labor, steam printing, mining and hundreds of other arts

have been brought to their present state by means of Watt's discoveries. In its adaptation to mills and factories steam is doubtless more costly than water-power; but, being independent of situation or season, it is in general circumstances preferable. Its placid steadiness, and the ease with which it may be managed, are also great recommendations in its favor. As a motive-power in the arts, steam takes the lead of all others, and, viewing it as an economizer of labor, it must assuredly be pronounced the greatest help of mankind. What electricity is doing or will do in the future is not pertinent to our present history.

It is in consequence of the improved mechanical arrangements and employment of inanimate forces in Great Britain that that comparatively small country has hitherto been enabled to manufacture goods cheaper, and with greater profit, than can be done by the largest and most populous countries in which mechanism is imperfect and labor performed exclusively by living agents.

The profits of manufactures so produced spread their beneficial influence over the whole mass of society, every one being less or more benefited. Thus almost all the luxuries and comforts of life, all the refinements of social existence, may be traced to the use of tools and machinery. Machinery is the result of mechanical skill, and mechanical skill is the result of experience and a long course of investigations into the workings of principles in nature which are hidden from the inattentive observer. Much of the present mechanical improvement is also owing to the pressure of necessities, or wants, which have always a tendency to stimulate the dormant powers of man. What are to be the ultimate limits and advantages of mechanical discoveries no one can foresee. The investigation of natural forces is yet far from being finished. Every day discloses some new scientific truth, which is forthwith impressed into the service of mankind and tends to diminish the sum of human drudgery. In this manner are we usefully taught that the study of nature forms a never-failing source of intellectual enjoyment and that "KNOWLEDGE IS POWER."

THE LIFE OF GEORGE STEPHENSON.

When we see a railway train drawn by a locomotive at the rate of forty miles an hour and carrying as many as five hundred passengers, how little are we apt to think that this marvel of science and art is due mainly to two men, who, in the outset of their career, occupied an obscure position—James Watt and George Stephenson, one a Scotsman, the other a native of the north of England, and both affording bright examples of what may be done in adverse circumstances by dint of well-directed labor, united with that degree of prudence without which ingenuity and toil are usually in vain. Of James Watt and the steam-engine we have already treated. Here we have to speak of Stephenson—plain old George, with his Northumbrian *burr*—the perfecter of the locomotive, but for whom

it might have been long before we should have seen a train running at the speed which now astonishes everybody.

George had a very humble beginning. His father, Robert Stephenson, with his wife Mabel, were a decent couple, living at a small colliery village, called Wylan, situated on the north bank of the Tyne, about eight miles from Newcastle. Here "old Bob," as Robert was usually styled by the neighbors, was employed as fireman to the engine which pumped water from the coal-pit, an employment of a toilsome kind, but requiring no great skill, and accordingly requited by the wage of a common laborer. It is said that Bob was descended from a Scottish family which had emigrated into Northumberland and had some pretensions to be of a superior class. But now the family had settled down as hand workers, a position in no respects dishonorable, for in every department of honest labor, no matter how humble, there is a dignity which nothing can overshadow. Lowly as was his situation in life, Robert Stephenson had tastes of no grovelling kind. Amiable in disposition, he was fond of animals, and loved to tell stories of one kind or other, which made him a great favorite with young persons. Mabel, his wife, good, "canny Mabel," is reported to have been a woman of a thoughtful, nervous temperament, and it is not unlikely that, in this as in many other instances, the mother communicated the impress of her character to her children.

Robert Stephenson had six children, of whom George, the hero of our story, was the second, born June 9, 1781. The lot of the family was to work, and work they did. We do not know whether the father, with all his tastes, had any wish to give his children a fair country education. Perhaps there were no schools near at hand, but be this as it may, Bob's children, like their neighbors in like circumstances, were left entirely to themselves in the way of book-learning. When George was about eight years of age his father removed to another colliery concern at Dewley Burn, where he filled a similar situation—that of shovelling in coal to a furnace which kept a steam-engine at work. It requires no stretch of imagination to fancy Bob here laboring daily in front of a glowing fire, with a big shovel in hand, clothed in coarse blue woollen trousers and shirt and wiping the drops of perspiration from his face with a bunch of coarse tow. Could any one, looking at that toiling, perspiring man, have supposed that he was the father of one

of England's great men? Bob, indeed, had not the slightest notion himself that he had a son who was to come to honor, and how could he?

Shortly after coming to Dewley Burn George was put to work, for he was eight years old and it was believed he could earn something to help on the family. A job was found for him; it was to herd a few cows, for which light duty he was paid twopence a day. We are now, as it were, introduced to George. He comes on the stage as a bare-legged herd-boy, driving cows, chasing butterflies and amusing himself by making water-mills with reeds and straws, and even going the length of modelling small steam-engines with clay. In these pursuits we have a glimpse of his mechanical turn. Often we see that boys take a bent towards what first excites their fancy. Brought up among coal-pits and pumps, and wheels and engines, it was not surprising that his mind should have a bias to mechanics. Some boys, indeed, are so dull or heedless that they may see the most curious works of art without giving them any sort of attention. But that was not George Stephenson's way. He pried into every mechanical contrivance that came under notice and acquired a knack of making things with no other help than an old knife. There was the poor boy's genius. He did not stare at things stupidly or with an affected air of indifference; neither did he pretend to take an interest in works of art in order to appear clever. He liked to work out his own ideas in his simple way, without a thought of results. From being a herd-boy he was promoted to lead horses when ploughing, hoe turnips and do other farm work, by which he rose from twopence to fourpence a day. He might have advanced to be an able-bodied ploughman, but his tastes did not lie in the agricultural line. What he wished was to be employed about a colliery, so as to be among bustle of wheels, gins and pulleys. Accordingly, quitting farm work, he got employment at Dewley Burn to drive a gin-horse, by which change he had another rise of twopence a day, his wages being now three shillings a week. In a short time he went as gin-horse driver to the colliery of Black Callerton, and as this was two miles from the parental home, he walked that distance morning and evening. This walk, however, was nothing to George, who was getting to be a big, stout boy, fond of rambling about after birds' nests and keeping tame rabbits and always taking a part in country sports. His next rise

was to act as an assistant fireman to his father at Dewley. Gladly he accepted this situation, for besides that he was allowed a shilling a day, he looked to being promoted to be engineman, which now, in his fourteenth year, was the height of his ambition. George did not long remain here. The coal-pit was wrought out and deserted, and the workmen and apparatus were removed to a colliery at Jolly's Close, a few miles distant. The Stephenson family removed with the others, and now occupied a cottage of only a single apartment, situated in a row of similar dwellings, with a run of water in front and heaps of debris all around.

In this miserably confined cottage there were accommodated the father and mother and six children, some of them pretty well grown up, and as all helped by their work there was nothing like poverty in the household. George and his elder brother James were assistant firemen, two younger boys performed some humble labor about the pit and two girls assisted their mother in household affairs. The total earnings of the father and sons amounted to from 35*s.* to 40*s.* a week. As this was equal to about £100 per annum, we are entitled to say that on that sum old Bob ought to have brought up his family respectably and given them at least the elements of education. But in this, as in thousands of cases, little else was thought of than to consume the whole weekly earnings in a coarse kind of plenty, leaving chance or the parish to provide for the future. No doubt, humble as it was, this was a most extravagant way of living, and it is obviously by such improvidence that many of the manual laboring classes keep themselves ever on the brink of poverty. The only excuse we can find for Bob and Mabel is that they did not know any better and, deprived of suitable house accommodation, had perhaps no heart to aspire to a more economic mode of life. Nor should we fail to remember that unless school instruction is obtruded in some shape or other on colliery villages and rural hamlets the residents can scarcely be blamed for their ignorance. Recent statutes and arrangements have probably done much to remedy this social defect among the Northumbrian colliers, and their children must in many respects be better looked to than was the fortune of their predecessors. From whatever cause, the want of education was a serious disadvantage to the young Stephensons. Not one of them was taught to read. George, at fifteen years of age, when working as assistant fireman, and forming one of a

family who were earning about a hundred a year, and paying no house-rent, did not know a letter. To one with much natural sagacity and an ambition to improve in circumstances we cannot easily conceive a more dreary condition. Let any one picture to himself the situation of a friendless lad, totally uneducated, living in a colliery village, and then try to conceive by what force of circumstances that lad was to attain to eminence in wealth and station and as a benefactor to mankind. In vain we make the effort, yet we shall see by what simple means Providence brings out great results, which no man can possibly discover by the most penetrating foresight.

Every man, no matter how lowly his lot, may be said to have a choice of two paths. He may fall in with the multitude of those who seek immediate self-indulgence and take no thought of the future; or, shrinking from this too common routine, he may, in the face of untold difficulties, make a sacrifice, for the sake of moral and intellectual improvement, with which not unusually comes an improvement in circumstances. We are now called on to notice which of the two paths was taken by George Stephenson. He chose immediate sacrifice, and lived to thank God for inspiring him to do so. Let us see how he set about it and how he carried it through. His duty consisted in attending to the furnace of one of those gigantic steam-engines which pumped water from a coal-pit. From Dewley he went to Mid Mill, and after that to the colliery of Throckley-bridge, at which his wages were twelve shillings a week. He felt he was getting on. It was a proud moment for him when one Saturday evening he got his first twelve shillings. "Now," said he, enthusiastically, "I am a made man for life."

While at this occupation he acquired a character for steadiness—that was a great point gained. The world is always groping about for steady men, and sometimes it is not easy getting hold of them. George was rigorously sober, and was never so happy as when he was at work, though it is also related of him that he took pleasure after work-hours in wrestling, putting or throwing the stone, and other feats of muscular skill. He possessed a powerful frame, and could lift heavy weights in a manner that was thought surprising. Rather a general favorite from his good-nature and dexterity at rustic sports, George likewise gave satisfaction to his employers, and, reputed as a clever, handy young man, was promoted to the

situation of engineman or plugman at Newburn. From looking after a furnace, he had now to attend to the working of a steam-engine, and to watch that the pumps were kept properly working. It was a post of responsibility, and not without trouble. If the pumps went wrong, he had to descend the pit, and do his best to rectify them by plugging; that is, stuffing any hole or crevice to make them draw; and if the defect was beyond his power of remedy, his duty was to report it to the chief engineer. In these services George took immense delight. He was now in his element; could handle, and scour, and work about among pistons, cylinders, wheels, levers, pumps, and other mechanical contrivances, and regarded the entire engine under his charge with feelings of keen admiration and affection. One likes to hear of this, for there is always something pleasing in the idea that a youth is an enthusiast in the kind of labor to which he has addressed himself, for there are then good hopes of his success.

George was so fond of his engine that he was never tired looking at it, as it worked with regularity and almost with sublimity the enormous pumps. Stooping like a giant, down went the great lever or pump-handle; a moment's pause ensues, and then without an effort up is drawn the prodigious volume of water, which runs away like a small river. In the constant contemplation of this magnificent triumph of art the mind of any one not lost to good feeling cannot fail to be elevated. At all events, George Stephenson experienced enviable sensations. Oh, that dear engine, how he did love it! to him, with its continuity and regularity of motion, it was like a living creature. As a mother fondles and dresses her child, so did George never tire fondling, dressing and undressing his engine. It was not enough that he saw the outside of the mechanism. It became a kind of hobby with him to take her—a steam-engine is *her*—to pieces, and after cleaning and examining all the parts, to put her again into working order. Then what joy, when the steam is let on, to see her begin to move—to come to life, as it were—and to commence her grand pumping operations.

When the engine was going in excellent trim, and nothing was wrong with the pumps, there was little to do. The mechanism went on of itself and required a look only now and then. Being so far an easy job for the engineman, there was time to spare. By way of occupying these idle minutes and hours George began to model

miniature steam-engines in clay, in which he had already some experience. It was a mere amusement, but it helped to fix shapes and proportions in his memory. While so engaged he was told of engines of a form and character he had never seen. They were not within reach, but were described in books. If he read these he would learn all about them. Alas! George, though now eighteen years of age, was still ignorant of the alphabet. He clearly saw that unless he learned to read he must inevitably stick where he was. The knowledge of past times, and much of the busy present, was shut out from him. With these convictions, it is not surprising that our hero resolved to learn to read—in fact, to put himself to school and so remedy, if it could be remedied, the neglect on this score of old Bob, his father.

Having settled in his own mind that he would go to school, cost what it might, George found out a poor teacher, named Robin Cowens, in the village of Walbottle, who agreed to give him lessons in the evening at the rate of threepence a week, a fee which he cheerfully paid. By Robin he was advanced so far as to be able to write his own name, which he did for the first time when he was nineteen years of age. To improve his acquirements he afterwards, in the winter of 1799, went to an evening school, kept by Andrew Robertson, a Scotch dominie, in the village of Newburn. Here he was advanced in a regular way to penmanship and arithmetic. But as there was not much time for arithmetical study during the limited school hours, George got questions in figures set on his slate, which next day he worked out while attending the engine. And that was all the education in the way of schooling he ever got. Very imperfect it was in quality and extent, but it admitted him within the portals of knowledge, and, getting that length, he was enabled to pick up and learn as he went on. The next event in his life was his removal, in 1801, to the Dolly pit, at Callerton, where he received somewhat higher wages, a point of some importance, for at this time the cost of living was very high. Perhaps it was owing to this dearth in food that George fell upon the expedient of devoting his leisure hours in the evening to the making and mending of shoes. Some may think that the craft of shoemaking was quite out of his way, but we have known several instances of shepherds and ploughmen being makers and menders of shoes in a homely style for their families, and, therefore, the "gentle craft" is not so very difficult to

learn as might be imagined. George Stephenson became a tolerable shoemaker, though he kept chiefly to cobbling or mending. If anything could have spurred him on, it was the desire to sole the shoes of his sweetheart, Fanny Henderson, and of these he is said to have made a "capital job." By means of his cobbling he was able to save a guinea, which is recorded as being the nest-egg of his fortune. Of course he never could have laid by so much as a guinea had he, like most of his acquaintances, frequented public houses and consumed quantities of beer. But no one ever saw him the worse for drink, and while others were soaking in taverns, or amusing themselves with cock-fighting and dog-fighting, he was at home, either trying to increase his sum of knowledge or applying himself to some useful occupation which was in itself an amusement. His sobriety and industry had their reward. He was enabled to furnish a house decently and to marry Fanny Henderson. The marriage was celebrated on November 28, 1802, and the pair betook themselves to the neat home that had been prepared at Willington Ballast Quay, a place on the Tyne, about six miles from Newcastle.

Settling down as a married man, George continued to devote leisure hours to study or to some handicraft employment. From making and mending shoes, he proceeded to mend clocks and became known among his neighbors as a wonderfully clever clock-doctor. It is said that he was led into this kind of employment by an accident. His chimney having gone on fire, the neighbors in putting it out deluged the house with water and damaged the eight-day clock. Handy at machinery, and wishing to save money, George determined to set the clock to rights. He took it to pieces, cleaned it, reorganized it and made it go as well as ever. There was a triumph! After this he was often employed as a repairer of clocks, by which he added a little to his income. On December 16, 1803, was born his only son Robert, who lived to be at the head of the railway engineering profession. But before either George or his son could arrive at distinction, there was not a little to be done. As a brakeman George had charge of the coal-lifting machinery at Willington, and subsequently at Killingworth, and in this department, as well as engineman, he gradually but surely gained the reputation of being an ingenious and trustworthy workman. At Killingworth, which is about seven miles north of Newcastle, he

suffered the great misfortune of losing his wife. This sad blow fell upon him in 1804, with his son still an infant.

The next thing we hear of him is that, leaving his child in charge of a neighbor, he went by invitation to superintend an engine at some works near Montrose, in Scotland, which journey, about a hundred and fifty miles, he performed on foot. Disagreeing after a short period with the owners, he trudged back to his home at Killingworth, bringing with him £28 as savings. One of the first things he did after his return was to succor his father, now an aged and blind man, whom, with his old mother, he placed in a comfortable cottage in his own neighborhood. Again he followed the employment of brakesman at West Moor pit, and was continuing to save, when, in 1807, his small accumulations were in a moment wholly swept away. He was drawn for the militia, and every shilling he had saved was paid away for a substitute. To be thrust back into poverty in so hateful a manner almost upset his philosophy, and he strongly meditated emigrating to America. Fortunately for England, his spirits revived, and he held on his course. In addressing a society of young operatives many years afterwards, he referred as follows to this dark period in his life: "Well do I remember the beginning of my career as an engineer, and the great perseverance that was required of me to get on. Not having served an apprenticeship, I had made up my mind to go to America, considering that no one in England would trust me to act as engineer. However, I was trusted in some small matters, and succeeded in giving satisfaction. Greater trusts were reposed in me, in which I also succeeded. Soon after, I commenced making the locomotive engine; and the results of my perseverance you have this day witnessed."

It says much for Stephenson, that under pinching difficulties he did not only take care of his old parents, but gave his child as good an education as was in his power. The want of learning he had himself acutely felt, and this deficiency, if at all practicable, he wished to avert from his son. In one of his public speeches late in life, he observed: "In the earlier period of my career, when Robert was a little boy, I saw how deficient I was in education, and I made up my mind that he should not labor under the same defect, but that I would put him to a good school, and give him a liberal training. I was, however, a poor man; and how do you think I managed? I betook myself to mending my neighbors' clocks and watches at

nights, after my daily labor was done, and thus I procured the means of educating my son."

In 1810, an opportunity occurred for George Stephenson signalizing himself. A badly-constructed steam-engine at Killingworth High pit could not do its work; one engineer after another tried to set it to rights, but all failed; and at last in despair they were glad to let "Geordie" try his hand, though with his reputation for cleverness they did not expect him to succeed. To their mortification and astonishment, he was perfectly successful. He took the engine to pieces, rearranged it skilfully, and set it to work in the most effectual manner. Besides receiving a present of £10 for this useful service, he was placed on the footing of a regular engineer, and afterwards consulted in cases of defective pumping apparatus.

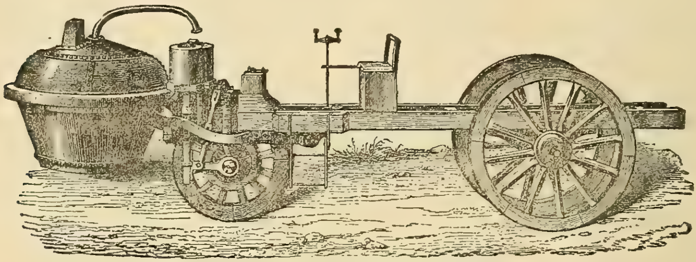
Although thus rising in public estimation, he still knew his deficiencies, and strove to improve by renewed evening studies. One of his acquaintances, named John Wigham, gave him some useful instructions in branches of arithmetic, of which he had an imperfect knowledge, and the two together, with the aid of books, spent many pleasant evenings in getting an insight into chemistry and other departments of practical science. His steadiness was at times sorely tried by the solicitations of neighbors in his own rank "to come and take a glass o' yill;" but resolutions to be temperate and to save for the sake of Robert's education, enabled him to withstand tempters of all kinds. By dint of such reserve, he was able to save a hundred guineas, which, in consequence of the demand for bullion during the French war, he sold to money-brokers for twenty-six shillings each. At intervals in his ordinary labor, he employed himself in building an oven and some additional rooms to his cottage, which he likewise rendered attractive by a garden cultured with his own hands.

The year 1812 marked Stephenson's rise to the position of a colliery engineer and planner of machinery for working pits and wheeling off coal. Proprietors and managers began to entertain a high idea of his qualities, which were obviously not those of a pretender. Referring to this period, when in 1835 he gave evidence before a select committee of the House of Commons on accidents in mines, he said: "After making some improvements in the steam-engines above ground, I was then requested by the manager of the colliery to go underground along with him to see if any improve-

ments could be made in the mines, by employing machinery as a substitute for manual labor and horse-power in bringing the coals out of the deeper workings of the mine. On my first going down the Killingworth pit, there was a steam-engine underground for the purpose of drawing water from a pit that was sunk at some distance from the first shaft. The Killingworth coal-field is considerably dislocated. After the colliery was opened, at a very short distance from the shaft, they met with one of those dislocations, or dikes, as they are called. The coal was thrown down about forty yards (or abruptly lay at that much lower level). Considerable time was spent in sinking another pit to this depth. And on my going down to examine the work, I proposed making the engine, which had been erected some time previously, to draw the coals up an inclined plane, which descended immediately from the place where it was fixed. A considerable change was accordingly made in the mode of working the colliery, not only in applying the machinery, but employing putters instead of horses in bringing the coals from the hewers; and by those changes the number of horses in the pit was reduced from one hundred to fifteen or sixteen. During the time I was engaged in making these important alterations, I went round the workings in the pit with the viewer almost every time that he went into the mine—not only at Killingworth, but at Mountmoor, Derwentcrook, Southmoor, all which collieries belonged to Lord Ravensworth and his partners; and the whole of the machinery in all these collieries was put under my charge."

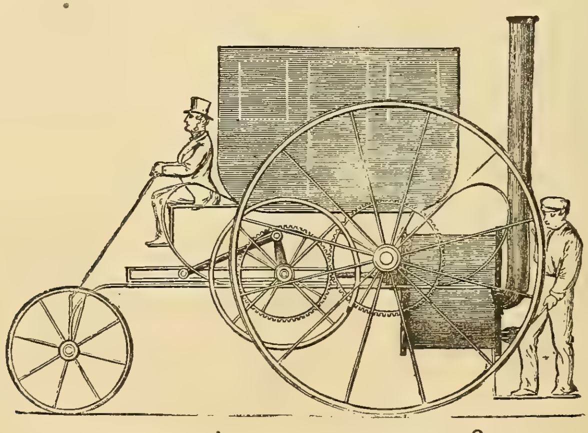
Leaving George engaged in these useful pursuits, which were intermingled with scientific studies with his son, when he came home from school at Newcastle, we may take a glance at the beginnings of railways and locomotives. It is certain there were railways of a rude kind in England as early as the commencement of the eighteenth century. The rails were at first of wood, then the wood was shod with slips of iron, and lastly, they were altogether rods or bars of iron. These old railways, which were better known by the name of tramways, were devised for the transit of coals from pits, the carriages being deep wooden wagons pulled by horses. Strangely enough, there was a railway of this kind across the fields from the coal-pits of Tranent to the small seaport Cockenzie, when the battle of Prestonpans was fought on the ground in 1745—which line of rails, honored by having been the site of Cope's can-

non, still exists. Wherever there were coal or iron mines, these tramways were introduced; nor could they fail to get into use, for a single horse could draw upon them a load that would have required twenty horses on a common highway.



CUGNOT'S ENGINE, 1770.

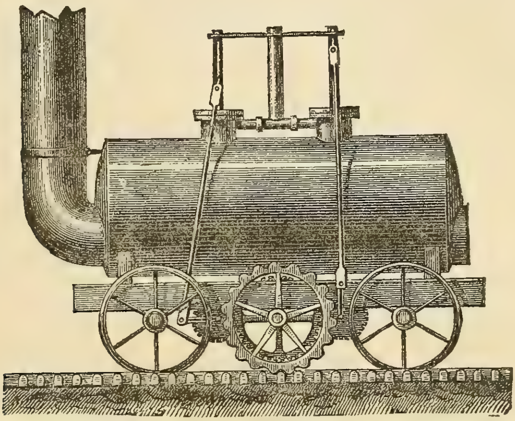
To Nicholas Joseph Cugnot, an officer of engineers in the French army, born 1725, is due the honor of the first successful application of steam to locomotion; it was designed for common roads and was in 1770 run at the rate of about four miles an hour in the neighborhood of Versailles, in the presence of a multitude of scientific and curious spectators.



TREVETHICK'S STEAM-CARRIAGE, 1803.

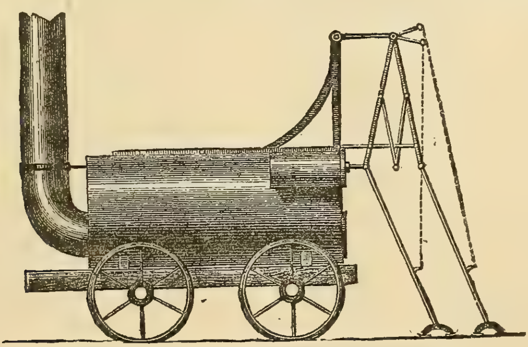
The credit of inventing a carriage moved by steam in England is due to Richard Trevethick, a Cornish tin-miner, and a clever but somewhat eccentric person. He made a steam-carriage to run on common roads or rails in 1802, and exhibited it in the metropolis. Improv-

ing on this, he, in 1804, completed a locomotive to draw coal on the Merthyr-Tydvil Railway in South Wales. It did its work well, drawing wagons with ten tons of iron at the rate of five miles an



BLENKINSOP'S TOOTH-WHEELED LOCOMOTIVE, 1811.

hour; but it was an ill-constructed machine, and having gone out of order, it was deserted by its inventor, and no more was heard of locomotives for some years. Next came the invention of Mr. Blenkinsop, who planned a locomotive for coal traction, which was

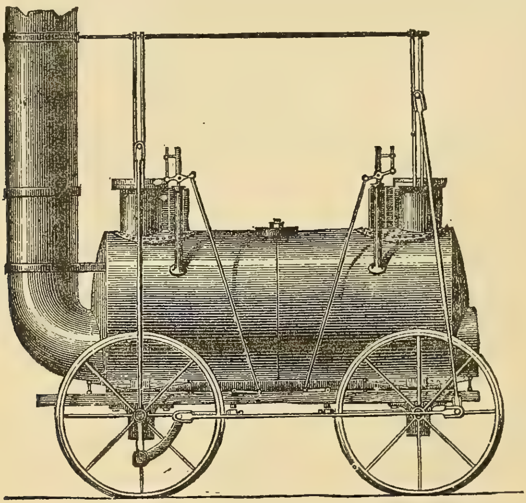


BRUNTON'S STILT LOCOMOTIVE, 1813.

used on a railway from Middleton Collieries to Leeds, and could haul as many as thirty loaded wagons at a speed of three and a quarter miles an hour. What long kept the invention in this backward state was the erroneous notion, that unless the locomotive had

wheels with cogs to pull against cogs in the railway, it would slip, and not get forward; and it was not until this fanciful idea was got rid of that much good was done with locomotive power. We find on record the description of a steam-engine moved by stilts or crutches which alternately pressed upon and lifted from the ground like the legs of a horse; this machine was patented and exhibited in 1813.

Finally, in 1813, Mr. Blackett, an engineer better advised than his predecessors, demonstrated that the enormous weight of the adhesion between the smooth rails and the equally smooth



STEPHENSON'S LOCOMOTIVE, 1815.

wheels would always suffice to prevent the wheels from slipping, and he established his theory by easy experiments. We may conceive that for about twenty years subsequent to 1813, there were many geniuses at work contriving improved locomotives, and among these none thought more diligently or deeply than George Stephenson. After a variety of experiments, he was satisfied with Blackett's theory that there would be sufficient adhesion in the wheels to overcome any tendency to slip; teeth or cogs were accordingly dismissed. In July, 1814, he was able to begin running his locomotive, called the *Blucher*, on the Killingworth Railway. It was still only a coal-drag, and at best a clumsy apparatus, but it hauled eight loaded wagons

weighing thirty tons, at about four miles an hour. This was undoubtedly a success; the thing could be done; yet, as the cost of working was about as great as that by horses, little was gained. There must be fresh trials. As by a flash of inspiration, Stephenson saw the leading defect and the method for curing it. The furnace wanted draught, which he gave by sending the waste steam into the chimney; and at once, by increased evolution of steam, the power of the engine was doubled or tripled. In 1815 he had a new locomotive at work, combining this and some minor improvements. Still, there was much to be done to perfect the machine. The cost of working was so considerable, that locomotive power did not meet with general approval; the fact was, that railways at this period were not so accurately finished as they now are, and smooth and easy running ought not to have been expected. It was only step by step that both rails and moving apparatus were brought to a comparatively perfect state.

At the Killingworth Colliery, Stephenson continued to plan his improvements, and also to advance in general knowledge in the society of his son, who, on leaving school in 1818, was placed as an apprentice to learn practically, underground, the business of a viewer of coal-mines; and in 1820 he went for a session of six months to the University of Edinburgh. The cost of this piece of education was £80, which the father could not well spare; but the prize for skill in mathematics which his son brought home with him at the end of the session was thought to be ample repayment. Acquiring a knowledge of railways, Robert was appointed to proceed to Colombia, South America, to superintend some railway operations. One day, previous to setting out, he dined with his father, and a young man named Dixon was of the party. An anecdote is related to show the strong faith which George Stephenson at this time entertained regarding railway progress. "Now, lads," said he to the two young men after dinner, "I will tell you that I think you will live to see the day, though I may not live so long, when railways will come to supersede almost all other methods of conveyance in this country—when mail-coaches will go by railway, and railways will become the great highway for the king and all his subjects. The time is coming when it will be cheaper for a workingman to travel on a railway than to walk on foot. I know there are great and almost insurmountable difficulties that will have to be

encountered; but what I have said will come to pass as sure as we live. I only wish I may live to see the day, though that I can scarcely hope for, as I know how slow all human progress is, and with what difficulty I have been able to get the locomotive adopted, notwithstanding my more than ten years' successful experiment at Killingworth."

Stephenson's attention had frequently been drawn to the deplorable destruction of life in coal-mines by the explosion of inflammable air or fire-damp. As early as 1815 he devised a safety-lamp to guard against those accidents. As it was about the same period that Dr. Clanny and Sir Humphry Davy invented their respective safety-lamps for the like purpose, it is not quite clear to whom the merit of the discovery should be assigned—though Stephenson's claim has been strongly insisted on. As this is not the proper place for debating the point, and, besides, as the matter is of inferior importance, we pass on to what is of real moment—Stephenson's perfecting of the locomotive; for on that his fame properly rests. Pursuing schemes of this kind, after parting with his son, his advancement was in no small degree owing to certain services in which he was engaged on the Stockton and Darlington Railway, a concern greatly promoted by Mr. Edward Pease, a man of property and intelligence in the district. The engineering of this railway was given up to Stephenson, and in some respects it became a model for railway works—the gauge of four feet eight and a half inches, which is now usually followed, having here been adopted in a regular manner in imitation of the old tramways. Already a manufactory of engines had been set up at Newcastle, in which George Stephenson was a partner, and from this establishment three locomotives were ordered by the directors of the Stockton and Darlington Railway Company; for in their act of Parliament they had taken power to employ steam in the traction of goods and passengers. The opening of this the first public railway took place on 27th September, 1825, in presence of an immense concourse of spectators. A local newspaper records the event as follows: "The signal being given, the engine started off with this immense train of carriages, and such was its velocity, that in some parts the speed was frequently twelve miles an hour; and at that time the number of passengers was counted to be 450, which, together with the coals, merchandise, and carriages, would amount to near ninety tons. The

engine, with its load, arrived at Darlington, a distance of eight and three-quarter miles, in sixty-five minutes. The six wagons loaded with coals, intended for Darlington, were then left behind; and obtaining a fresh supply of water, and arranging the procession to accommodate a band of music and numerous passengers from Darlington, the engine set off again, and arrived at Stockton in three hours and seven minutes, including stoppages, the distance being nearly twelve miles." The drawing of about 600 passengers, as there appear to have been in the train, at the rate of four miles an hour, was thought very marvellous. A month later a regular passenger-coach, called the *Experiment*, was placed on the line; it was drawn by a horse in two hours. The haulage of coal only was effected by the locomotive. It was evident that the making of engines was still in its infancy. Stephenson, at his manufactory, continued to carry out improvements, in which he was assisted by his son, on his return from South America in 1827.

When the project of the Manchester and Liverpool Railway was before Parliament in 1825, George Stephenson, in the face of no little browbeating from ignorant and interested opponents, gave good evidence respecting the practicability and safety of drawing passenger-trains with locomotives, though still speaking diffidently as to a speed of more than from fifteen to twenty miles an hour. Few things are more amusing than the real or affected incredulity of members of the legislature at this time as to railway transit, notwithstanding that the propulsion of coal-trains by locomotive power had been satisfactorily demonstrated. It is always, however, easy to find fault and to disbelieve; and the opposition which railways at first encountered is no way singular. Stephenson's assertion during his examination before a committee of the House, that it would not be difficult to make a locomotive travel fifteen or twenty miles an hour, provoked one of the members to reply that the engineer could only be fit for a lunatic asylum.*

Parliamentary sanction once obtained, the Liverpool and Manchester Railway Company set to work upon their novel and important undertaking—novel, inasmuch as its scheme and magnitude

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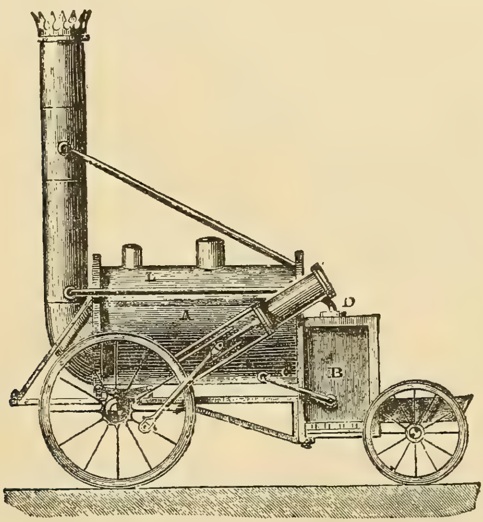
* It was on this occasion that Stephenson was asked by a member of the Parliamentary Committee, " Mr. Stephenson, what would happen if a cow got on the track, with your engine running at fifteen miles an hour? " To this Stephenson replied, " It would be awkward for the coo."

exceeded all that had been previously attempted of a similar nature. Stephenson, who had already won a reputation, was appointed engineer, at £1000 a year, and a chief point determined on was, that the line should be as nearly as possible straight between the two towns. In the carrying out of this design the series of "engineering difficulties" was first encountered, the overcoming of which has called forth an amount of scientific knowledge, of invention, ingenuity, and mechanical hardihood unprecedented in the history of human labor. Hills were to be pierced or cut through, embankments raised, viaducts built, and four miles of watery and spongy bog, called Chat Moss, converted into a hardened road—all which was successfully effected.

The line being at length completed, the directors offered a prize of £500 for the best locomotive that could be brought forward to compete in running on a certain day. It was stipulated that the engine should consume its own smoke; be not more than six tons in weight; and be able to draw twenty tons, including tender and water-tank, at ten miles an hour; be supported on springs, and rest on six wheels; must have two safety-valves; the pressure of steam should not exceed fifty pounds to the square inch; and the price of the engine was not to be above £550. Stephenson determined to compete, and built an engine called the *Rocket* for the purpose. The day of trial was the 8th of October, 1829, when three engines were brought forward. Stephenson was there with his *Rocket*, Hackworth with the *Sanspareil*, and Braithwaite and Ericcson with the *Novelty*. The test assigned was to run a distance of thirty miles at not less than ten miles an hour, backwards and forwards along a two-mile level near Rainhill, with a load three times the weight of the engine. The *Novelty*, after running twice along the level, was disabled by failure of the boiler-plates, and withdrawn. The *Sanspareil* traversed eight times at a speed of nearly fifteen miles an hour, when it was stopped by derangement of the machinery. The *Rocket* was the only one to stand the test and satisfy the conditions. This engine travelled over the stipulated thirty miles in two hours and seven minutes nearly, with a speed at times of twenty-nine miles an hour, and at the slowest nearly twelve; in the latter case exceeding the advertised maximum; in the former, tripling it. Here was a result! An achievement so surprising, so unexpected, as to be almost incredible. Was it not a delusion?—had it been really accomplished?—and could it be done again?

The prize of £500 was at once awarded to the makers of the *Rocket.* Their engine was not only remarkable for its speed, but also for the contrivances by which that speed was attained. Most important among them was the introduction of tubes passing from end to end of the boiler, by means of which so great an additional surface was exposed to the radiant heat of the fire, that steam was generated much more rapidly, and a higher temperature maintained at a smaller expenditure of fuel than usual. The tubular boiler was indeed the grand fact of the experiment. Without tubes, steam could never have been produced with the rapidity and heat essential



STEPHENSON'S LOCOMOTIVE ENGINE, THE "ROCKET," 1829.*

to quick locomotion. In more senses than one, the trial of the three locomotives in October, 1829, marks an epoch. By burning coke instead of coal the stipulated suppression of smoke was effected; the quantity consumed by the *Rocket* during the experiment was half a ton. The coke and water were carried in a tender attached to the engine.

On the 15th of September, 1830, the railway was opened. The

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* A, the boiler, 6 feet long, 3 feet 4 inches in diameter. B, the fire-box enclosed in a casing 3 inches wide, containing water. C, a water pipe communicating between the casing and the boiler. D, a steam-pipe between the same. E, two pipes (one from each cylinder) for throwing the exhaust steam into the chimney.

two great towns, with due regard to the importance of the event, made preparations for it with a spirit and liberality worthy of their wealth and enterprise. Members of the government, and distinguished individuals from various quarters, were invited to be present at the opening. On the memorable day a train was formed of eight locomotives and twenty-eight carriages, in which were seated the eminent visitors and other persons present on the occasion, to the number of 600. The *Northumbrian*, one of the most powerful of the engines, took the lead, followed by the train, which, as it rolled proudly onwards, impressed all beholders with a grand idea of the energies of art, and of the power destined soon afterwards to effect the greatest of civil revolutions. At Parkfield, seventeen miles from Manchester, a halt was made to replenish the water-tanks, when the accident occurred by which Mr. Huskisson lost his life, and tempered the triumph by a general sentiment of regret. The proceedings, however, though subdued, were carried out in accordance with the arrangements prescribed.

Business began the next day. The *Northumbrian* drew a train with 130 passengers from Liverpool to Manchester in one hour and fifty minutes; and before the close of the week six trains daily were regularly running on the line. The surprise and excitement already created were further increased when one of the locomotives by itself travelled the thirty-one miles in less than an hour. Of the thirty stage-coaches which had plied between the two towns, all but one went off the road very soon after the opening, and their 500 passengers multiplied at once into 1600. In December commenced the transport of goods and merchandise, and afforded further cause of astonishment; for a loaded train, weighing eighty tons, was drawn by the *Planet* engine at from twelve to sixteen miles an hour. In February, 1831, the *Samson* accomplished a greater feat, having conveyed 164½ tons from Liverpool to Manchester in two hours and a half, including stoppages—as much work as could have been performed by seventy horses.

There are some who will remember the wonder and excitement created by these results in all parts of the kingdom. The facts could not be disputed. Neither the laws of nature nor science could be brought to accord with the views of those who saw in the new agencies the elements of downfall and decay. Even the company had gone surprisingly astray in their calculations. Believing

that the greater part of their business and of their revenue would be derived from the transport of heavy goods, they had set down £20,000 a year only as the estimated return from passenger traffic; and scarcely a week had passed before they became aware of the fact, as agreeable as it was unexpected, that passengers brought the greatest return. The whole number conveyed from the time of opening to the end of the year—three months and a half—was more than 71,000. This line, as is well known, now forms part of that vast system, the London and Northwestern Railway.

These successes placed George Stephenson in an eminent position in the engineering world. He was sought after for various undertakings; the business with which he was connected at Newcastle increased; and, in short, he was, as far as worldly consideration and circumstances are concerned, a "made man." His steadiness, perseverance, and skill had been acknowledged and rewarded. He and his son further perfected the locomotive, which he lived to see running at upwards of forty miles an hour. In 1837, he removed to Tapton Hall, a residence near Chesterfield, and in 1840, he intimated his design of retiring from his more active professional pursuits. He, however, did not subside into idleness or indifference; but gave time to various railway matters, and took pleasure in attending public meetings of mechanics' institutes. It was a great day for him, the 18th of June, 1844, when the first train came without break from London to Newcastle in the space of nine hours. At the festival on that day at Newcastle, to signalize the event, all eyes were turned on old George Stephenson, when, in reply to a complimentary speech of Mr. Liddell, M. P., he gave the following brief but interesting account of his career.

"As the honorable member has referred to the engineering efforts of my early days, it may not be amiss if I say a few words to you on that subject, more especially for the encouragement of my younger friends. Mr. Liddell has told you that in my early days I worked at an engine on a coal-pit. I had then to work early and late, and my employment was a most laborious one. For about twenty years I had often to rise to my labor at one and two o'clock in the morning, and worked until late at night. Time rolled on, and I had the happiness to make some improvements in engine-work. The company will be gratified when I tell them that the first locomotive that I made was at Killingworth Colliery. The owners

were pleased with what I had done in the collieries; and I then proposed to make an engine to work upon the smooth rails. It was with Lord Ravensworth's money that my first locomotive was built. Yes, Lord Ravensworth and his partners were the first gentlemen to intrust me with money to make a locomotive. That was more than thirty years ago; and we first called it 'My Lord.' I then stated to some of my friends, now living, that those high velocities with which we are now so familiar would, sooner or later, be attained, and that there was no limit to the speed of such an engine, provided the works could be made to stand; but nobody would believe me at that time. The engines could not perform the high velocities now reached, when they were first invented; but, by their superior construction, an immense speed is now capable of being obtained. In what has been done under my management, the merit is only in part my own. Throughout, I have been most ably seconded and assisted by my son. In the early period of my career, and when he was a little boy, I felt how deficient I was in education, and made up my mind that I would put him to a good school. I determined that he should have as liberal a training as I could afford to give him. I was, however, a poor man; and how do you think I managed? I betook myself to mending my neighbors' clocks and watches at night, after my daily labor was done. By this means I saved money, which I put by; and, in course of time, I was thus enabled to give my son a good education. While quite a boy he assisted me, and became a companion to me. He got an appointment as under-viewer at Killingworth; and at nights, when we came home, we worked together at our engineering. I got leave from my employers to go from Killingworth to lay down a railway at Hetton, and next to Darlington for a like purpose; and I finished both railways. After that I went to Liverpool to plan a line to Manchester. The directors of that undertaking thought ten miles an hour would be a maximum speed for the locomotive engine, and I pledged myself to attain that speed. I said I had no doubt the locomotive might be made to go much faster, but we had better be moderate at the beginning. The directors said I was quite right; for if, when they went to parliament, I talked of going at a greater rate than ten miles an hour, I should put a cross on the concern! It was not an easy task for me to keep the engine down to ten miles an hour; but it must be done, and I did my best. I had to

place myself in the most unpleasant of all positions—the witness-box of a parliamentary committee. I was not long in it, I assure you, before I began to wish for a hole to creep out at. I could not find words to satisfy either the committee or myself, or even to make them understand my meaning. Some said: 'He's a foreigner.' 'No,' others replied; 'he's mad.' But I put up with every rebuff and went on with my plans, determined not to be put down. Assistance gradually increased; great improvements were made in the locomotive; until to-day, a train which started from London in the morning has brought me in the afternoon to my native soil, and enabled me to meet again many faces with which I am familiar, and which I am exceedingly pleased to see once more."

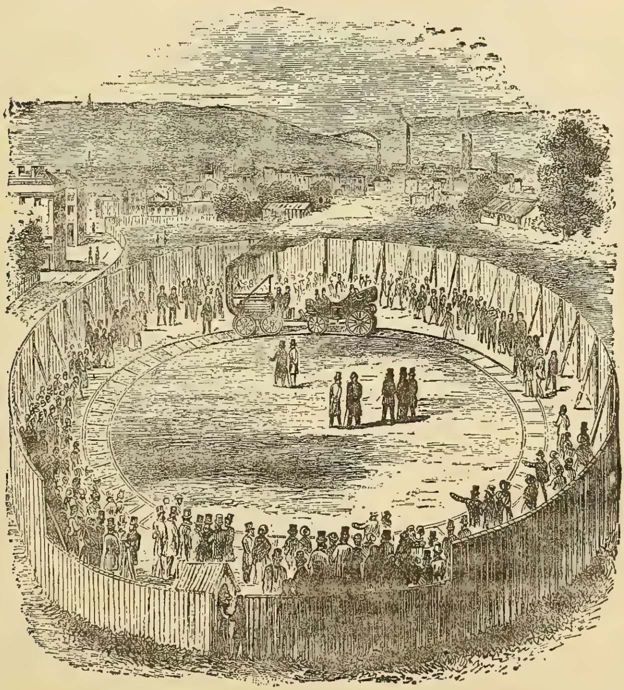
Besides planning several railways after this period, and giving evidence respecting projects of this kind before parliamentary committees, Stephenson several times visited the continent to be consulted respecting lines of railway; on one of which occasions he had an interview, along with his friend Mr. Sopwith, with the king of the Belgians. He likewise continued to be a prominent man at public demonstrations connected with the opening of railways, one of the latest of these festivities being at the opening of the Trent Valley line in June 1847, when he was complimented by Sir Robert Peel, and compared by him to Julius Agricola, the maker of Roman roads in Britain. George was now accustomed to the language of compliment from classes of men who formerly treated his theories with derision. In replying to Sir Robert Peel's flattering remarks, he could not refrain from noticing this change of sentiment. "When," he said, "I look back to the time when I first projected a locomotive railway in this neighborhood, I cannot but feel astonished at the opinions which then prevailed. We were told, even by celebrated engineers, that it would be impossible ever to establish railways. Judge, then, how proud must now be the feelings of one who, foreseeing the results of railways, has risen from the lower ranks on their success! I may venture to make a reference to what the Right Honorable Baronet said relative to Julius Agricola and a direct line. If Julius Agricola laid down the most direct lines, it must be recollected that he had no heavy goods-trains to provide for, and gradients were of no consequence. The line that general took was probably very good for his troops, where the hills would serve to establish his watches; but such lines would be in no

way applicable at the present day, where the road is covered with long goods-trains propelled by the locomotive. What we require now is a road with such gradients that locomotives shall be able to carry the heaviest loads at the least expense. The Right Honorable Baronet will excuse me if I say that to have a line that is direct is not the main thing. Had he studied the laws of practical mechanics as I have done, he would doubtless have regarded good gradients as one of the most important considerations in a railway." This last remark has been amply verified. Railways are now made with gradients which would not formerly have been attempted; but the heavy expense incurred on account of fuel and tear and wear of machinery to overcome the ascents forms a serious deduction from revenue.

At home, in the close of his days, George Stephenson occupied himself with his birds and other animals, for which he had a great fondness; nor did he take less pleasure in his garden and the rearing of flowers and vegetables. Occasionally he visited the scenes of his youth among the collieries about Newcastle, at all times taking an interest in the welfare of the workmen, and never feeling ashamed of recognizing old acquaintances. Though often invited to the houses of persons of distinction, he acknowledged he had no wish to figure in what he called fine company. It is said that he was beset by projectors of all kinds for the sake of his advice; and that the young likewise besought his counsel as to their proposed professional career, which he gave always cheerfully, except when these youthful aspirants were affectedly dressed, and put on airs contrary to George's notions of propriety. To a young applicant of this stamp his candor was probably not very agreeable, but may have been salutary. "I hope you will excuse me; I am a plain-spoken person, and I am sorry to see a nice-looking and rather clever young man like you disfigured with that fine-patterned waistcoat and all these chains and fang-dangs. If I, sir, had bothered my head with such things when at your age, I should not have been where I am now."

With this love of simplicity, and universally respected, George Stephenson closed his useful career. He died 12th August, 1848, aged 67. In the preceding sketch we have touched merely on the chief incidents in his biography, which we commend for perusal in

either of the admirable works composed by Mr. Smiles. The mantle of George Stephenson fell on his son, Robert; and how he added lustre to the family name is well known. Besides several great railway undertakings, of which he was engineer, he designed the High Level Bridge across the Tyne at Newcastle, the Conway and Britannia Tubular Bridges in North Wales, and that still more magnificent work of art, the Tubular Bridge, nearly two miles in length, across the St. Lawrence at Montreal—in all which works, however, he was ably assisted by subordinates; nor should it be omitted that to William Fairbairn, of Manchester, is generally imputed the invention of the tubular system of bridge-building. In 1844 he entered parliament as member for Whitby. This distinguished son survived his father only eleven years. He died in 1859, aged 56, and was honored with a public funeral and interment in Westminster Abbey. If the traveller by railway wishes to see a lasting monument to George and Robert Stephenson, he has only to look around!



TREVETHICK'S CIRCULAR RAILWAY AT LONDON, 1808.

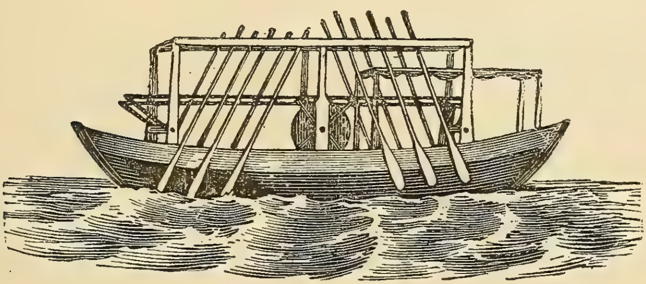
THE SHARE AND CLAIMS OF AMERICANS AND OTHERS IN THE DISCOVERY AND APPLICATION OF STEAM.

The main story related above is from English records, and we have deemed it necessary to glance at the share claimed for America in this important introduction of steam for mechanical purposes.

Reviewing the history of the discovery of steam, as described in the two biographies given above, we have to conclude that, although the fact of steam as a mighty power was known before the Christian era,* yet for practical use it was worthless till Papin made his dis-

* The engineer, noting the curious things in bronze and in copper, exhumed at Pompeii and gathered together in the Museo Borbonica at Naples, will linger near a small vessel for heating water, little more than a foot high, in which are combined nearly all the principles involved in the modern vertical steam-boiler—fire-box, smoke-flue through

covery as related at page xix, *supra*. Savary seems to have taken it up where Papin left it, and Newcomen improved on Savary, till, as we see at page xxiii, *supra*, Newcomen's engine fell into the hands of Watt for repair, and it at once "became a living thing." The scramble for the application of Watt's discovery to locomotives and navigation, whether from the improved experience of Savary or Newcomen or the perfected discovery of Watt, numbers among the scramblers such names as Murdoch, Symington, Miller, Fitch, Rumsey, Fulton, Kingsley, Trevethick, Telford, Blenkensop, Blackett, Ericsson, Hackwah, Bunstal, and several in France and Italy, and the culminating success of the result of all these competitors was



FITCH'S STEAMBOAT.

the *Rocket* locomotive at Rainhill, and Fulton's steamboat, the *Clermont*, at New York.

JOHN FITCH, born at Windsor, Conn., 1743, was an original genius. In 1787 he launched a steam-packet (it had paddles at the side) at Philadelphia, which reached a speed of thirteen miles per hour, and, having obtained by letters patent the exclusive right of steam navigation in New Jersey, Pennsylvania and Delaware, he built a boat to convey passengers on the Delaware river for hire, which proved a commercial failure. He died 1798.

JAMES RUMSEY was born in Maryland, 1743, studied mechanics and became an inventor. In 1784 (twenty-three years before Fulton

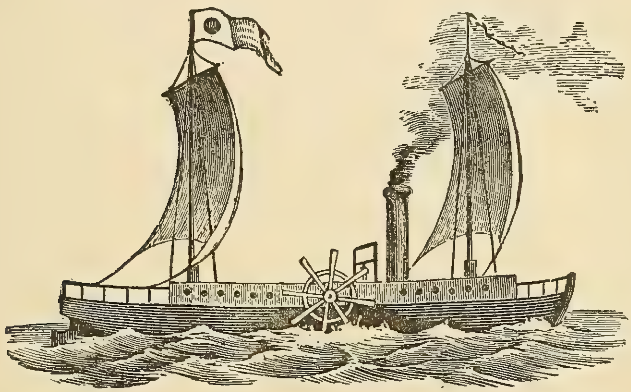
the top and fire-door at the side, all complete—and strange to say, this little thing has a *water-grate*, made of small tubes crossing the fire-box at the bottom, an idea that has been patented twenty times over, in one shape or another, within the period of the history of the steam-engine.—*Joseph Harrison, Jr.*

built the *Clermont*) he exhibited on the Potomac, in the presence of General Washington, a boat propelled by machinery. In 1786 he exhibited a boat in which a pump worked by steam-power drove a stream of water from the stern and thus furnished the motive-power. A society was formed to aid his project, of which Franklin was a member. His death occurred in 1792, while he was making further experiments.

APOLLOS KINGSLEY, a young man, of Hartford, Conn., about the year 1798, made and propelled through the streets of that city a steam locomotive, which he then said would in future be the means of propelling the mail stages, etc. He was not credited, died soon after, and all then went for nothing.

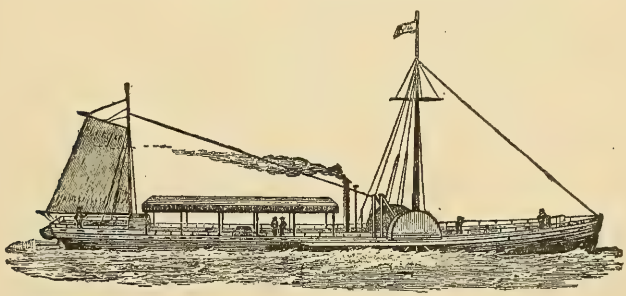
ROBERT FULTON was born in Pennsylvania, 1765. He received a good school education. When he was old enough his mother apprenticed him to a jeweller in Philadelphia. In addition to his labors at this trade he devoted himself to painting, and the sale of his portraits and landscapes enabled him, in the space of four years, to purchase a small farm, on which he placed his mother, his father being dead. At the age of twenty-two he proceeded to London, where he studied painting under West; but, after several years spent thus, he felt that this was not his true vocation. Accordingly, abandoning painting, he applied himself wholly to mechanics. Some works he performed in Devonshire obtained him the patronage of the Duke of Bridgewater and likewise that of the Earl of Stanhope. Accepting an invitation from the United States minister at Paris, he proceeded to that city in 1796 and remained there for seven years, devoting himself to new projects and inventions. Amongst his inventions here was the *nautilus*, or sub-marine boat, intended to be used in naval warfare, which he in vain sought the French government to accept. Nor was he more successful with the British government, which he next tried, though commissions were appointed in both cases to test the value of his invention. Having failed in this matter, he next turned his attention to a subject that had frequently occupied his mind before and about which he had written a treatise in 1793, viz., the application of steam to navigation. In 1803 he constructed a small steamboat, and his experiments with it on the Seine were attended with great success. He returned to New York in 1806 and pursued his experiments there. In 1807 he launched a steam-vessel, the *Clermont*, upon the

Hudson, which made a successful start in the presence of thousands of astonished spectators. From this period steamers (for the construction of which Fulton received a patent from the Legislature) came into pretty general use upon the rivers of the United States.



FULTON'S STEAMBOAT, 1803.

Although Fulton was not the first to apply steam to navigation, as a steam-vessel, Symington's, had been tried upon the Forth and Clyde canal as early as 1789, and Miller, near Dumfries, 1790, yet he was the first to apply it with any degree of success to STEAM



THE CLERMONT, 1807.

NAVIGATION. His reputation was now firmly established, and he was employed by the United States government in the execution of various projects with reference to canals and other words. In 1814 he obtained the consent of the Legislature to construct a steam-

frigate, which was launched in the following year. Though the labors of Fulton were attended with such great success, various lawsuits in which he was engaged in reference to the use of some of his patents prevented him from ever becoming wealthy, and anxiety, as well as excessive application, tended to shorten his days. His death, in 1815, produced extraordinary demonstrations of mourning throughout the United States.

* OLIVER EVANS was born 1755 in the State of Delaware and was educated in the common schools of Philadelphia, to which city his parents had removed shortly after his birth. He was apprenticed to a wheelwright, and when twenty-two years old he invented a machine for card teeth, which superseded hand work. In his thirty-first year, 1786, Evans petitioned the Legislature of Pennsylvania for the exclusive right to use his improvements on flouring-mills and steam-carriages in Pennsylvania. In the following year he presented the same petition to the Legislature of Maryland. In the former case he was only successful so far as to obtain the privilege for the mill improvements, his representations respecting steam-carriages savoring too much of insanity to deserve notice.

He was more fortunate in Maryland, for although the steam project was laughed at, yet one of his friends, a member, very judiciously observed that *the grant could injure no one, for he did not think that any man in the world had ever thought of such a thing before. He therefore wished the encouragement might be afforded, as there was a prospect of its producing something useful.* The exclusive privilege was granted, and after this Mr. Evans considered himself bound in honor to the State of Maryland to produce a steam-carriage as soon as his means would permit him.

To Oliver Evans must be awarded the credit of having built and put in operation the first practically useful high-pressure steam-engine, using steam at 100 pounds pressure to the square inch, or more, and dispensing with the complicated condensing apparatus of Watt.† The high-pressure engine of Evans had advantages for us in its greater simplicity and cheapness, and ever since his day it has continued the standard steam-engine for land purposes in America.

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* We are indebted for this notice of Oliver Evans to a valuable work, *The Locomotive Engine and Philadelphia's Share in its Early Improvement*, by Joseph Harrison, Jr.

† Watt's patent for the condensing apparatus was dated 1766.

English writers have tried to detract from the fame of Oliver Evans, but it is well known that early in his engineering life he sent drawings and specifications of his engines, etc., to England by the hands of Mr. Joseph Stacey Sampson, of Boston. It is well known also that these drawings, etc., were shown to and copied by engineers in England, and from this period dates the introduction into Europe of the first really useful high-pressure steam-engine, now so generally applied to locomotive and other purposes.

Basing his hopes of success on the use of the high-pressure engine in his steam-carriage, Oliver Evans, notwithstanding the opposition and even the derision of his best friends, and of almost every one, made earnest efforts in the beginning of this century to carry out his design for building his favorite machine, but without success. He had a good friend in Mr. Robert Patterson, the Professor of Mathematics in the University of Pennsylvania, who recommended the plan as highly worthy of notice and who wished to see it tried. Evans' plan was shown to Mr. B. H. Latrobe, a scientific gentleman of great eminence in his day, who publicly pronounced them chimerical and who attempted to demonstrate their absurdity in his report to the American Philosophical Society on *Steam-Engines*, in which he also undertook to show the impossibility of making steamboats useful.

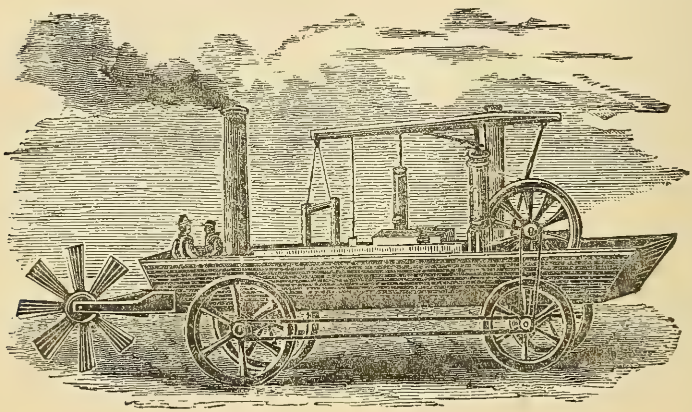
In Mr. Latrobe's report Mr. Evans was said to be seized with the "*steam mania*," which was no doubt most true. To the credit of our then and now most learned society, the portion of Mr. Latrobe's report which reflected so harshly upon Mr. Evans was rejected, the members conceiving that they had no right to set up their opinions as an obstacle in the way of an effort towards improvements that might prove valuable for transport on land. The society did, however, admit in the report the strictures on steamboats.

Oliver Evans never succeeded in constructing a steam-carriage such as he had contemplated. It was commenced, and unaided he spent much time and money in fruitless efforts to complete it. Finding himself likely to be impoverished if he persisted in the scheme, he finally abandoned it, and devoted his time thereafter to the manufacture of his high-pressure steam-engine and his improved milling machinery. Previously, however, to the final abandonment of his favorite project, Oliver Evans, on the 25th of September, 1804, submitted to the Lancaster Turnpike Company a statement of the

cost of and probable profits of a steam-carriage to carry *one hundred* barrels of flour *fifty* miles in twenty-four hours, tending to show also that one such carriage would make more net profit on a good turnpike road than ten wagons drawn by five horses each.

He offered to build a steam-carriage at a very low price. Evans' statement to the turnpike company closed as follows: "It is too much for an individual to put in operation every improvement which he may invent. I have no doubt but that my engines will propel boats against the currents of the Mississippi, and wagons on turnpike roads with great profit. I now call upon those whose interest it is, to carry this invention into effect."

Oliver Evans, in the early part of 1804, came nearest to realizing



OLIVER EVANS' "ORUCTOR AMPHIBOLIS."

his favorite idea, in obtaining an order from the Board of Health of Philadelphia to construct at his foundry (a mile and a half from the water) a dredging machine for cleaning docks, the first one ever contrived for dredging by steam, now so common.

To this machine Evans gave the name of "Oructor Amphibolis," or Amphibious Digger, and he determined, when it was completed, to propel it from his work shop to the Schuylkill river, which was successfully done, to the astonishment of a crowd of people gathered together to see it fail. When launched, a paddle-wheel, previously arranged, was put in motion at the stern, and again it was propelled by steam to the Delaware, leaving all vessels half-way behind in the trip, the wind being ahead.

This result Evans hoped would have settled the minds of doubters as to the value of steam as a *motor* on land and water. But his attempt at moving so great a weight on land was ridiculed, no allowance being made by the *hinderers* of that day for the disproportion of power to load,—rudeness in applying the force of steam for its propulsion, or for the ill form of the boat. A rude cut of the "Oructor Amphibolis" is still extant, which shows a common scow, mounted on four wooden wheels, with power applied to the whole number of the wheels by the use of leathern belts.

Evans, after this experiment, willing to meet the question in any way, silenced the *carpers* around him by offering a wager, that for $3,000 he would make a steam-carriage that would run on a level road as swift as the fastest horse they could produce. His bet met with no takers.

This movement by steam power of Oliver Evans' dredging machine on land was, without any doubt, the first application of steam to a carriage in America, and in fact the first locomotive engine.* It was a more important experiment than any that had preceded it, anywhere in the same direction.

Oliver Evans' conceptions respecting the power of steam, many of them practically exemplified by him, reflect great credit on his sagacity as an engineer, and many of his predictions in regard to its great value, particularly for land transport, may well be termed prophetic.

In the early part of this century he publicly stated that "The time will come when people will travel in stages moved by steam-engines from city to city, almost as fast as birds fly,—fifteen or twenty miles an hour. Passing through the air with such velocity, changing the scene in such rapid succession, will be the most exhilarating exercise." "*A steam-carriage will set out from Washington in the morning,—the passengers will breakfast in Baltimore,—dine in Philadelphia, and sup in New York the same day.*" † "To accomplish this, two sets of railways will be required, laid so nearly level as not to deviate more than two degrees from a horizontal line,—made of wood or iron, on smooth paths of broken stone or gravel, with a rail to

* Du Cognot's carriage was made in 1770; see page xlviii. Mr. Harrison probably was not aware of this.

† We now (1888) lunch at 2 o'clock in Washington, and dine at 8 o'clock the same afternoon in New York.

guide the carriages, so that they may pass each other in different directions, and travel by night as well as day."

Much stress is laid upon these early efforts of Oliver Evans towards the introduction of steam for land and water transportation, and much space has been given here to set them forth. With no light to guide him (for it is fair to suppose that he knew nothing of the little that had been done up to his day in Europe), how his trumpet-tones ring out in the words above quoted (date 1804), compared with the "uncertain sound" made by the English engineers in 1829. *They*, with a quarter of a century of later experience, during which period much had been done to improve and develop the locomotive engine, then no new thing, nor was it barren of useful practical results, hesitated and doubted in their course. *He*, with no misgivings as to the future, and with no dimmed vision, saw with prophetic eyes all that we now see. To *him* the present picture, in all its grandeur and importance, glowed in broad sunlight. In the history of these efforts of Oliver Evans it is noteworthy, and most creditable to our sister State of Maryland, that that commonwealth extended to him the first public encouragement in his steam-carriage project.

Again our enterprising neighbor was first in the field, since become so important, for we find that in March, 1827, the State of Maryland chartered the first railway company in America, and in 1828 her citizens commenced the construction of the Baltimore and Ohio Railway, aiming to cross the Alleghenies; certainly the greatest railway scheme that had been thought of up to that date, and now, in its completed state, a triumph of railway engineering. To this first effort to make a great railway in the United States, and its influence upon the history of the locomotive, reference will be made hereafter.

Oliver Evans died in 1819, and his plans for a steam-carriage died with him, and although he produced nothing practically useful in the great idea of his life, he has left behind him an enduring monument in his grain and flour machinery.

The materials for the history of the next attempt at making a steam-carriage in America, eight or nine years after the death of Oliver Evans, are not very full. At this period (1828) a steam-carriage to run on a common road was projected by some parties in our city whose names cannot now be easily reached. This steam-

carriage was built at the small engineering establishment of Nicholas and James Johnson, then doing business in Penn street, in the old district of Kensington, just above Cohocksink creek, Philadelphia.

An eye-witness of its construction, and who saw it running under steam on several of its trials, describes it as an oddly-arranged and rudely-constructed machine. It is believed to have had but a single cylinder, set horizontally, with connecting-rod attachment to a single crank at the middle of the driving-axle. Its two driving-wheels were made of wood, the same as an ordinary road-wagon, and were of large diameter, certainly not less than eight feet. It had two smaller wheels in front, arranged in the usual manner of a road-wagon, for guiding the movement of the machine. It had an upright boiler hung on behind, shaped like a huge bottle; the smoke-pipe, coming out through the centre at the top, formed the neck of the bottle. Its safety-valve was held down by a weight and lever, and it was somewhat amusing to see the *puff, puff, puff* of the safety-valve as the machine jolted over the rough street. This was before the days of spring-balances for holding down the safety-valves of locomotives.

On its trials, made on the unpaved streets of the neighborhood in which it was built, this steam-carriage showed an evident lack of boiler as well as cylinder power. It would, however, run continuously for some time and surmount considerable elevations in the roads. It was sometimes a little unmanageable in the steering-apparatus, and on one of its trials, in running over the High bridge and turning up Brown street, its course could not be changed quick enough, and before it could be stopped, it had mounted the curbstone, smashed the awning-posts, and had made a demonstration against the bulk-window of a house at the southwest corner of Brown and Oak streets.

After this mishap it was not seen on the streets again, nor is it known what ultimately became of it. This last effort may be classed in some respects no doubt with what Oliver Evans promised in his mind to carry out, and it is very evident that up to its time no great amount of knowledge, or of practical or theoretical skill, had been brought to bear upon the construction of locomotives in Philadelphia. No books were as yet published in America describing the locomotive, or telling what had been done in land transport by

steam in Europe. The trials on the Liverpool and Manchester Railway in 1829 had not been made, and a better result could have hardly been expected than this recorded above.

With the wonderful success of the *Rocket* in October, 1829, the attention of our engineers and capitalists was strongly turned towards this new revelation in land transport, that had so suddenly flashed upon the world. It was a matter of the greatest importance to us, with our rich lands everywhere teeming with produce, the producers meanwhile crying aloud for better means to get their harvests to market, and for getting our people, too, more speedily from point to point, that we should know more of this new thing, and if it fulfilled its promise, to get the advantage of it as soon as possible.

It is true that the river, the canal, and the turnpike road have done good service in the past; but they did not keep pace with the growing wants of the country. The river, Nature's own free highway, is, when navigable, often hindered by flood and frost, by currents and by drought, nor does it run everywhere, or always where it would best conduce to man's use and benefit. The slow, plodding canal did its work cheaply, and with nothing better it must have continued the favorite means for inland trade. But canals are only possible where water can be had in abundance to keep them full, and with winter's cold to interrupt their movement, they are practically useless for half the year. Their capacity, at best, is limited, too, in many ways. The turnpike road, most useful in its place, had a very narrow limit of usefulness, when the means to do the carrying trade of a continent were to be attained. Man's restless nature longed for and demanded something better than the river, the canal, or the turnpike road, and this had been found in the RAILROAD and the LOCOMOTIVE. It did not take long, therefore, to come to a decision that railways* *must* be built, and the locomotive brought into use, and that speedily.

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* The first RAILROAD built in America was on Beacon Hill, near Boston, Mass., in 1807. It was built by Silas Whitney to haul gravel from the top of the hill to the bottom, and consisted of two tracks. The next was from Thomas Leiper's stone-quarries on Crum creek, Delaware county, Pa., to his landing on Ridley creek, a distance of about one mile, in 1809. The next railroad (five-foot gauge) was that from the granite-quarries at Quincy to the Neponset river in Massachusetts, a distance of about three miles, which was commenced in 1826 and finished in 1827. In January, 1826, was com-

It has been seen that Maryland took the lead, and she had her great road well under way before other States looked the question fairly in the face. South Carolina followed the lead of Maryland, and granted a charter at an early period to the South Carolina Railway, intending to cross the whole breadth of the State, and ultimately aiming to reach the far west.

Signs of railway movement were seen in Pennsylvania, Delaware and New Jersey, and in New York and New England. The Columbia Railroad (a State work) was projected in Pennsylvania at this time, and the Philadelphia, Germantown and Norristown Railroad was begun in Philadelphia. New Jersey had chartered and commenced her road from Camden to Amboy, and little Delaware, ahead of all the States north and east of her, had two miles of the Newcastle and Frenchtown Railroaa ready for use on the 4th of July, 1831.

The South Carolina Railroad was amongst the first to encourage the manufacture of American locomotives, and Mr. Horatio Allen, one of the first engineers of the country, designed and had built, in 1830–31, at the West Point foundry in New York, the first locomotives it is believed that were ever ordered and made in the United States for regular railroad traffic

Other engines subsequently built in New York after designs by

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menced the novel "mule-road," nine miles in length, connecting the Summit Hill coal-mines, back of Mauch Chunk, with the Lehigh river. It was in operation May, 1827.

On August 8, 1829, the first locomotive that ever turned a driving-wheel on a railroad-track in America was run at Honesdale, Pa., on the newly-finished road that connected the Lackawanna coal-fields with tide water on the Hudson Canal. The road in question was the first of any general commercial importance ever built in this country, and inaugurated the economical system of inclined planes, since adopted by engineers wherever practicable. It is claimed by some that at about the same time Peter Cooper, of New York, built the first American locomotive—the *Tom Thumb*—in 1829, and tried it on the Baltimore and Ohio Railroad, thirteen miles of which had then been laid. It did not work quite so well as he desired, though it was capable of locomotion, and he remodelled it. On August 28, 1830, it made a perfectly satisfactory trip, running thirteen miles in an hour and a quarter. The *Tom Thumb*, however, was only an experiment. The first American locomotive built for actual service was the *Best Friend of Charleston*, ordered March 1, 1830, by the South Carolina Railroad Company, of the West Point Foundry, New York. It was completed in October, 1830, and shipped to Charleston. It made its trial trip November 2, 1830, and worked satisfactorily. The second American engine for actual service was built by the same parties for the same company, and was put on the railroad in March, 1831.—*From Watson's Annals of Philadelphia.*

Mr. Allen, did good service on the South Carolina Railroad, and it is curious to note that in these later engines was embodied every valuable point of the *Fairlie* engine, now making so much noise in England. These points being the use of a vibrating truck at both ends with cylinders thereon, fire-box in the middle, with flues from fire-box to each end of the boiler, double smoke-box and double chimney, with fire-door at the side of fire-box, flexible steam and exhaust pipe, etc.*

The directors of the Baltimore and Ohio Railroad in January, 1831, by advice of Mr. Jonathan Knight, of Pennsylvania, still taking the lead in the railroad movement, and with the desire to encourage American skill, adopted the same plan that had been so successfully carried out at Liverpool in 1829 and offered a premium of $4,000 for the best American locomotive.

At this period in this history more mind and more practical knowledge had been brought out in Philadelphia aiming towards the improvement of the locomotive engine. In March, 1830, Colonel Stephen H. Long, of the United States Topographical Engineers, a gentleman of high scientific culture and noted for his originality, obtained a charter from the State of Pennsylvania, incorporating the "American Steam-Carriage Company," and soon thereafter commenced the construction of a locomotive in Philadelphia. This engine was designed somewhat after the then recently improved locomotives made in England, but had several original points.

This first engine of Colonel Long was placed, when finished, upon the Newcastle and Frenchtown Railroad, and the Hon. Wm. D. Lewis has furnished the following account of its trial at various times on that road, with which he at that period was connected in an official capacity.

* The first locomotive ever run on a railroad in America was undoubtedly the *Lion*, one of two engines built at Stourbridge, in England, under the direction of Mr. Horatio Allen and imported into this country in the autumn of 1829 for the Delaware and Hudson Railroad in the State of New York. Mr. Allen, in describing its first movement, says that he was the only person upon the engine at the time, and he certainly made the first trip by steam on an American railroad. The *Lion*, built before the *Rocket*, had vertical cylinders, arranged somewhat after the manner of the old style of Killingworth or Stockton and Darlington engines, with four driving-wheels, all connected. The boiler of this engine approached closely to the locomotive boiler of the present day, in having a fire-box with five flues leading to the smoke-box, this latter feature being, in fact, the first step towards the present multi-tubular boiler.

COLONEL LONG'S LOCOMOTIVE.

"On the 4th of July, 1831, two miles of rail being laid on the Newcastle and Frenchtown Railroad, Colonel Long made trial on it of his locomotive which weighed about three and one-half tons. The first effort was not a success, the failure being attributed to lack of capacity to furnish a sufficient supply of steam. It would go well enough for a while, but the steam could not be kept up. The next day the colonel had better luck, his engine then going to the end of our rails and back, drawing two passenger cars packed with people (say seventy or eighty) with apparent ease, and it had fifty pounds of steam at the end of the experiment.

"The colonel, however, was not satisfied with it, and the machine was brought to Philadelphia again and a new boiler was constructed for it at Rush & Muhlenburgh's works at Bush Hill. This engine was again taken to Newcastle and tried upon the road, but it again failed. It would go very well for a time, but on the 31st of October, 1831, a pipe was burst and it became disabled. This being repaired, two days thereafter another trial was made, but with equal want of success, which was ascribed to lack of power as well as of specific gravity. Alone this engine went very well and rapidly, say at the rate of twenty-five miles an hour, but it would not draw a satisfactory burden.

"Soon after the above date Colonel Long removed his engine from the road and I do not know what became of it afterwards." Mr. Lewis adds: "The above memoranda I now enclose of the trials of Colonel Long's locomotive in 1831 are made from a book in which all the facts I give you were set down contemporaneously with their occurrence." This unsuccessful attempt of Colonel Long was, up to its date, much the most important movement that had yet been made in Philadelphia towards the improvement of the locomotive, and as such it deserves special notice. It was furthermore not without its value in inducing him thereafter to pursue the subject to much better results. Had Colonel Long more faithfully copied the English engine of his day he would have had better success in his first effort; but he, as with all our Philadelphia engineers and mechanics at that time and in the succeeding years, aimed at making an American locomotive.

Whilst Colonel Long was engaged in the construction of his engine Matthias W. Baldwin, a name that has since become so famous in

the history of the improvements and in the manufacture of the locomotive in Philadelphia, was engaged in making a model locomotive for the Philadelphia Museum. In this work Mr. Baldwin was assisted by that highly eminent practical mechanic and engineer, Franklin Peale, then manager of the museum.

To gratify the curiosity of the public to know more of this new thing, this little engine was placed upon a track laid around the rooms of the museum, in what was then the Arcade, in Chestnut street, above Sixth, and where it was first put in operation on April 25, 1831. It made the circuit of the museum rooms many times during the day and evening for several months, drawing behind it two miniature passenger cars, with seats in each for four persons, but often carrying twice that number, in a manner highly gratifying to the public, who attended in crowds to witness for the first time in this city and State the effect of steam in railroad transportation. This little engine was perhaps the first made expressly to draw passengers that had ever been placed on a railroad in America.*

With the knowledge of the success that had been achieved in England, the desire to *know* more of, and the necessity to *have* as speedily as possible, this new power soon became a paramount question in the Middle, Northern, Southern and Eastern States of the Union.

The reward of $4,000 offered for the best American locomotive by the directors of the Baltimore and Ohio Railroad, brought out many competitors, and in after years several very curious specimens of locomotive engineering might be seen in one of the shops of

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*In rendering a just meed of credit to all who aided in the early development of the locomotive in Philadelphia, it is not out of place here to introduce the following extract from an obituary notice of Franklin Peale, read before the American Philosophical Society at a meeting on December 16, 1870, by his friend, Robert Patterson, a grandson of Robert Patterson, who had been Oliver Evans' firm friend in the latter's efforts in the last century to introduce a steam-carriage. "It was while engaged at the museum that Mr. Peale placed there a miniature locomotive, the first seen in this country and manufactured by his friend, M. W. Baldwin, on a plan agreed upon between Mr. Peale and his friend. It was put in operation on a track, making the circuit of the Arcade, in which the museum then was, drawing two miniature cars with seats for four passengers. The valuable aid of Mr. Peale was afterwards given to Mr. Baldwin in the construction of the locomotive for the Philadelphia and Germantown Railroad, built in 1832, the success of which led to the establishment of Mr. Baldwin in the great business of his life—the foundation of the Baldwin Locomotive Works."

this road. An eye-witness of these efforts in 1834 describes one which sported two walking beams, precisely like some river steamers of the present day. Mr. Phineas Davis, of York, Pennsylvania, bore off the prize offered by the Baltimore and Ohio Railroad, and his engine was the only one that survived the trial. With the Peter Cooper upright tubular boiler adapted thereto, this locomotive of Mr. Davis became for several years the type of engine for the road upon which it won its fame, and to this day some of these Grasshopper or Crab engines, as they are sometimes called, may be seen doing good service at the Camden Street station, in Baltimore.*

Philadelphia mechanics, following the lead of their predecessors in the same field, entered with zeal into the Baltimore contest. An engine was built by a Mr. Childs, who had invented a rotary engine which in a small model promised good results, and an engine of about fifty horse-power on this rotary plan was built and sent to Baltimore for trial. A record of its performance cannot now be easily reached, but it is known that it was never heard of as a practically useful engine after this time.

The second locomotive built in Philadelphia, to compete at Baltimore, was designed by Mr. Stacey Costell, a man of great originality as a mechanic, and the inventor of a novelty in the shape of a vibrating cylinder steam-engine that had some reputation in its day, and has come down to our time exactly in the little engine now sold in the toy-shops for a dollar.

The Costell locomotive had four connected driving-wheels, of about thirty-six inches in diameter, with two six-inch cylinders of twelve-inch stroke. The cylinders were attached to right-angled cranks on the ends of a counter shaft, from which shaft spur gearing connected with one of the axles. The boiler was of the Cornish type, with fire inside of an internal straight flue. Behind the bridge wall of this boiler, and inside the flue, water tubes were placed at intervals, crossing each other after the manner of the English Gal-

* Previous to the competition on the Baltimore Railroad, Mr. Peter Cooper, since deceased, the well-known New York philanthropist, sent to Baltimore a small engine not larger than an ordinary hand-car. This little locomotive had an upright tubular boiler (no doubt the first of its kind), which developed such good steam-making qualities as to induce Mr. Phineas Davis to purchase the Cooper patent right, and boilers of this kind were used by Mr. Davis in the locomotives built by him subsequent to the competitive trial on the Baltimore and Ohio Railroad.

loway boiler of the present day. The peculiar arrangement of this engine made it possible to use a very simple and efficient mode of reversement by the use of a disc between the steam pipe and the cylinders, arranged with certain openings which changed the direction of the steam and exhaust by the movement of this disc against a face on the steam pipe near the cylinder, something after the manner of a two-way cock.

It is not known whether this locomotive of Costell's went to Baltimore or not. It is known, however, to have been tried on the Columbia road in 1833 or 1834, but its success was not very striking, and it was subsequently broken up. The boiler of the Costell locomotive had very good steam-making qualities. It was used for a long time as a stationary engine boiler.

The third engine begun in Philadelphia for the Baltimore trial in 1831 was after a design of Mr. Thomas Holloway, an engineer of some reputation forty years ago as a builder of river steamboat engines. This engine was put in hand, but was never completed.

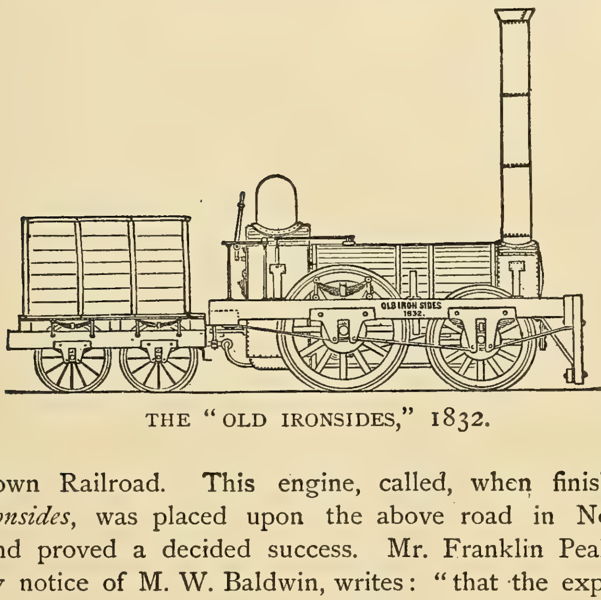
Something was gained even by the failures that are here related, and these early self-reliant efforts show with what tenacity Philadelphia engineers clung to the idea of building an original locomotive, and it will be seen hereafter that a type of locomotive essentially American was ultimately the result.

Whilst these movements towards the improvement of the locomotive were going on amongst us, the desire to have the railroad in every section of the country became more and more fully confirmed. The railway from Newcastle to Frenchtown, sixteen miles in length, was finished in the winter of 1831 and 1832, and two locomotives built by Robert Stephenson at Newcastle-upon-Tyne were imported to be run upon this line, which made then an important link in the chain of passenger travel between New York and Washington. In this case, as in several others in the early history of the railroad in the United States, this new element came in as an adjunct mainly of the river steamboats, and was considered most useful in superseding the old stage coach in connecting river to river, and bay to bay.

That the railway would supersede the steamboat for passenger travel, and the canal for heavy transport, was not dreamed of in the early day of the new power.

When the English locomotives were landed at Newcastle, Del-

aware, it became necessary to select a skilled mechanic to put them together as speedily as possible. Through the agency of Mr. Wm. D. Lewis, a most active director of the Newcastle and Frenchtown Railroad Company, this task was assigned to Matthias W. Baldwin. These engines were of the most improved English type, and were greatly superior in design and workmanship to any that had then been seen in this country. In putting these engines together, Mr. Baldwin had all the advantage of handling their parts and studying their proportions, and in making drawings therefrom. This proved of great service to him when he received an order, in the spring of 1832, to build a locomotive for the Philadelphia, Germantown and



THE "OLD IRONSIDES," 1832.

Norristown Railroad. This engine, called, when finished, the *Old Ironsides*, was placed upon the above road in November, 1832, and proved a decided success. Mr. Franklin Peale, in an obituary notice of M. W. Baldwin, writes: "that the experiments made with the *Ironsides* were eminently successful, realizing the sensation of a flight through the air of fifty or sixty miles an hour." The *Old Ironsides*, in its general arrangement, was a pretty close copy of the English engines on the Newcastle and Frenchtown Railroad, but with changes that were really improvements. The reversing gear was a novelty in the locomotive, although the same mode had been long used for steam ferryboats on the Delaware. This arrangement consisted of a single eccentric with a double-latch eccentric rod, gearing alternately on pins on the upper and

lower ends of the arms of a rock shaft. This mode of reversing was used in the Baldwin locomotives for many years after the *Old Ironsides* was built.

It is creditable to Mr. Baldwin as an engineer that the *Old Ironsides* was the first and last of his imitations of the English locomotives. He, following the bent of all the Philadelphia engineers and mechanics that had entered the field, aimed, too, at making an American locomotive; and his second engine, and those succeeding it, were entirely different in design from the *Old Ironsides.*

Following the success of this first locomotive, other orders soon flowed in upon Mr. Baldwin, and on these later engines many valuable improvements were introduced, of which mention will be made hereafter.

Colonel Stephen H. Long, nothing daunted or discouraged by the unsuccessful results of his first engine in 1831, renewed his efforts, and under the firm of Long & Norris, the successors of the American Steam Carriage Company, commenced building a locomotive in 1832, subsequently called the *Black Hawk.* This engine, when finished, was run for some time on the Philadelphia and Germantown Railroad, and did good service in the summer of 1833, in competition with Baldwin's *Ironsides.* The *Black Hawk* burnt anthracite coal with some success, using the natural draught only, which was increased, for the first time in a locomotive, by the use of a very high chimney, arranged to lower from an altitude of at least twenty feet from the rails, to a height which enabled it to go under the bridges crossing the railroad. In all of Colonel Long's experiments he seems to have discarded the steam jet, or exhaust for exciting the fire. The *Black Hawk* had several striking peculiarities beside the one just mentioned. The boiler, a very good and a very safe one, was unlike any that had preceded it, in having the fire-box arranged without a roof, being merely formed of water sides, and in being made in a detached piece from the waist or cylindrical part. The cylinder portion of the boiler consisted of two cylinders about twenty inches in diameter, and these, lying close together, were bolted to the rear water side, and thus covered the open top, and their lower half-diameters thereby became the roof of the fire-box. A notch was cut half way through these two cylinders on their lower half diameters, about midway of the length of the fire-box, directly over the fire, and

from these notches flues of about two inches diameter passed through the water space of each cylinder portion of the boiler to the smoke-box. These flues were about seven feet in length. Besides passing through the flues, the fire passed also under the lower halves of the cylinder portions of the boiler, a double sheet-iron casing, filled between with clay, forming the lower portion of the flue and connecting it with the smoke-box.

The *Black Hawk* rested on four wheels, the driving-wheels, about four and a half feet diameter, being in front of the fire-box. The guide-wheels were about three feet diameter. Inside cylinders were used, and these required a double crank axle, and the latter, forged solid, could not easily be had. Colonel Long overcame this difficulty by making his driving axle in three pieces, with two bearings on each, and with separate cranks keyed on to the ends of each portion of the axle, with shackle or crank pins arranged after the manner of the modern side-wheel steamer shafts.

Flanged tires of wrought iron could not then be had easily, and this was overcome in the *Black Hawk* by making the tread for the wheels of two narrow bands, shrunk side by side on the wooden rim, with a flat ring, forming the flange, bolted on the side of the wheel. Springs were only admissible over the front axle, and to save shocks in the rear, the after or fire-box portion of the boiler was suspended upon springs. The camb cut-off, then much in vogue on the engines of the Mississippi steamers, was used in the *Black Hawk*. Other locomotives, mainly after the design of the *Black Hawk*, were built by Long & Norris, and by William Norris & Co., in 1834, but they were not greatly successful.

With the firm of William Norris & Co., Colonel Long retired from the manufacture of locomotives in Philadelphia, and his name was not thereafter heard of in connection with its improvement. On the retirement of Colonel Long, William Norris, a gentleman then with no acknowledged pretensions as a mechanic or engineer, brought other skill to his assistance, and after several not very successful efforts with engines of a design more like those that had succeeded of other makers, brought out an engine, in 1836, called the *George Washington*, the success of which laid the foundation of the large business done for thirty years thereafter at Bush Hill, Philadelphia, by William Norris, and subsequently by his brother, Richard Norris.

The *George Washington* was a six-wheel engine with outside cylinders, having one pair of driving-wheels, four feet in diameter, forward of the fire-box, with vibrating truck, for turning curves, in front. This engine weighed somewhat over fourteen thousand pounds, and a large proportion of the whole weight rested on the single pair of driving wheels.

This locomotive, when put upon the Columbia road (now Pennsylvania Central), did apparently, the impossible feat of running up the old inclined plane at Peter's Island, 2,800 feet long, with a rise of one foot in fourteen, drawing a load of more than nineteen thousand pounds above the weight of the engine, and this, too, at a speed of fifteen miles per hour. This was no doubt impossible, if the simple elements of the calculation are only considered. But there was a point in this experiment, well known to experts at the time, which *did* make it possible, even by calculation; and this point consisted in the amount of extra weight that was thrown upon the drivers by the action of the draft link connecting the tender with the engine,—the result being that about *all* the weight of the locomotive rested upon the drivers, less the weight of the truck frame and wheels in front. This most extraordinary feat, a writer on the subject says, "took the engineering world by storm, and was hardly credited."

The *George Washington*, an heir of the earlier efforts of Colonel Long, was unquestionably a good and well-made engine, and greatly superior to any that had preceded it from the Norris Works. The fame this engine earned, led to large orders in the United States, and several locomotives of like character were ordered for England and for Germany.

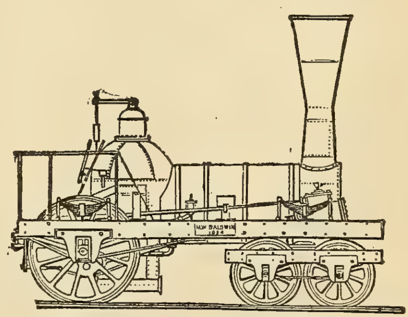
Improvements were made from time to time in the Norris locomotives—the establishment fairly holding its own with its rivals until the Norris Works ceased to exist about 1866 or '67. Mr. William Norris, who in connection with Colonel Long had founded the works at Philadelphia, at one time commenced the building of locomotives at Vienna, Austria, but with no very great success; and after his return ceased his connection with the Norris Works. At the epoch from 1833 to 1837, the Norris and Baldwin engines had each their advantages and defects.

The *Norris* engine, as it was at the commencement of 1837, may be described as follows: The boiler was of the dome pattern, known

in England as Bury's, and used by that maker in 1830; the framing was of wrought iron. The cylinders were placed outside of, and were fastened to the smoke-box as well as to the frame. The engine was supported on one pair of driving-wheels, placed forward of the fire-box, and on a swivelling four-wheeled truck placed under the smoke-box. The centre of the truck being so much in advance of the point of bearing of the leading wheels in the English engines of that day, there was considerably greater weight placed upon the driving-wheels in proportion to the whole weight, while it was not unusual to adjust the draw bar so as to throw a portion of the weight of the tender upon the hinder end of the engine when drawing its load. These engines used four excentrics with latches. Hand levers were used for putting the valve rods into gear when standing. The valve motion was efficient, as the performances of these engines fully attested.

The *Baldwin* engine of the same period had a similar boiler, and somewhat similar position of and fastening of the cylinders. The driving-wheels were placed behind the fire-box, the usual truck being placed under the smoke-box. These engines ran steadily, owing to their extended wheel-base, although they did not have the weight on the drivers, and the consequent adhesive power of the Norris engine. The framing was of wood covered with iron plates, and was placed outside the wheels.

The driving-wheels had two outside bearings. The cylinders, although outside of the smoke-box, were placed so as to give a connection to the crank inside of the driving-wheels. The crank was formed in the driving-axle, but instead of being made as a complete double or full crank, the neck, to which the connecting-rod was attached, was extended through and fastened into a hole in the driving-wheel, the distance from the centre being equal to the throw of the crank. A simple straight pin, fitted to the centre of the wheel, and extending outwards, formed an outside bearing for the



BALDWIN ENGINE, 1834.

axles. This device of Mr. Baldwin's was most ingenious and efficient. It simplified by more than one-half the making of a crank-shaft, and increased its strength, and at the same time caused the thrust of the cylinder to act close to the driving-wheel inside, in the same manner as the outside crank-pin.

With the introduction of the outside cylinder, this mode of making a crank-axle has gone into disuse. The guide-bar for the cross-head, which had a double V top and bottom, was clasped by the cross-head, and being hollow and with valve-chamber attached, was made to serve the purpose of a force pump. The valve-gear, already described, was placed under the foot-board, and although efficient, was cramped for room, the excentric rods consequently being rather too short.

In workmanship and proportion of parts the Baldwin engine was the superior of the two classes of locomotives that had then become in their manufacture an important feature in the trade of Philadelphia.

M. W. Baldwin, in 1834 and 1837, had greatly the advantage of the Norris establishment, as he had had from the first, in being a good practical machinist himself, and in having had some experience in steam-engine building previous to the making of the *Ironsides* in 1832; whereas, William Norris, after Colonel Long retired, in 1833–34, having personally little engineering knowledge and no practical skill in engine building, was left entirely dependent upon hired assistance, which at that time, in the construction of the locomotive, was most difficult if not almost impossible to obtain.

Mr. Baldwin had also the great advantage of better workshops and better tools than his early competitor at the commencement of this new business; hence his success was at once more decided, and the improvements in his locomotives, both in design and in workmanship, were more important from the beginning. It is needless to speak of the "Baldwin Locomotive Works," Burnham, Parry, Williams & Co., of to-day.

With a record of fifty years, during the early period of which it passed successfully through many vicissitudes, it maintains its well-earned character of the first locomotive manufactory, both in quantity and quality, in this country; and it is doubtful whether it is not now the equal to, if not the superior, in these particulars, of any establishment doing similar work in the world.

The Baldwin engine of 1837, with its driving-axle behind the fire-box, was steady at high speeds, but with insufficient adhesion to the rails.

The Norris engine, of the same date, having a great proportion of the weight overhanging the driving-axle, and having adhesion equal to its cylinder power, was unsteady on the rails. Improvement rested between the two systems of Baldwin and of Norris.

In the spring of 1835 the firm of Garrett & Eastwick, then making steam-engines and light machinery in Philadelphia, desiring to engage in this new business, obtained an order for building a locomotive engine for the Beaver Meadow Railroad. This firm, having no practical knowledge of locomotive engine building, had called to their assistance, as foreman, Mr. Joseph Harrison, Jr., a young man of twenty-five, with ten years' experience in the workshop, and a good practical workman, who had been employed for nearly two years as a journeyman in the Norris works, and who when there had been schooled amidst the indifferent successes or real failures of Long & Norris, and Wm. Norris & Co. The first locomotive designed under the above auspices was called, when finished, the *Samuel D. Ingham*, after the President of the road. It had outside cylinder connections, then not much in vogue—running-gear after the Baldwin type, with one pair of driving-wheels behind the fire-box, and with four-wheel truck in front. It had the dome or "Bury" boiler.

This engine had some points about it which differed from any locomotive that had preceded it. Its most distinguishing feature was an ingenious and entirely original mode of reversement, invented and patented by Mr. Andrew M. Eastwick, the junior member of the firm. It is scarcely possible to give a correct idea of this device without a model or drawings, but its principle consisted in the introduction of a movable block or slide, called a reversing valve, between the usual slide valve and the opening through the cylinder face. This reversing valve had an opening through it vertically for the exhaust, and two sets of steam openings, corresponding, when placed opposite thereto, to the openings on the cylinder face. One set, called direct openings, passed directly through the valve, and when fixed for going forward made the usual channels to the cylinder. The second set of openings through the reversing valve, called indirect openings, coming into play when the

engine moved backwards, passed from the upper surface of this valve but half way through it, and thence were diverted laterally to the side of the valve, and thence along the side and again laterally, came out of the under side where the reversing valve rested against the valve face of the cylinder, directly opposite a second indirect opening on the upper surface of this valve.

When the reversing valves were fixed for going forward the direct openings were then exactly over the steam openings on the cylinder, whilst the indirect openings came over the solid surface of the cylinder face and were entirely out of use. The exhaust opening through the reversing valve in this case came directly opposite the exhaust opening on the cylinder. The slide valve, never detached from the excentric, moved always over both sets of openings in the usual way. Moving the reversing valve to the opposite end of the steam chest from where it had been placed in going forward, and the case was different. Then steam entering the reversing valve at the upper side, instead of going directly into the cylinder as before, was diverted in the manner just described and came out at the cylinder face at the opposite end from which it had entered on the slide valve face on the upper side of the reversing valve, and thus the direction of the engine was changed from forwards to backwards, or *vice versa*, without detaching or reattaching any of the moving parts of the valve gear.

The principle and action of Mr. Eastwick's invention may be guessed at from what has been described, although its detail may not be so easily made out.

This new arrangement, neat and efficient as it was, had its defects, which no doubt interfered with its general use. It increased by the thickness of the reversing block the length of the steam openings in going forward, and further increased their length in going backwards. It also prevented the use of a long lap on the slide valve, for any lead of the excentric in going forward, causing a corresponding delay in receiving steam in moving backward. In reviewing these defects the beauty and originality of Mr. Eastwick's device must not be overlooked.

Nothing for the same purpose so novel in its mode of action had preceded or has succeeded this invention of a Philadelphia mechanic, and it is doubtful whether any locomotive has since been made with so few moving parts as this first engine of Garrett & Eastwick.

This engine had for the first time the rear platform covered with a roof to protect the engineman and the fireman from the weather.

The success of the *Samuel D. Ingham* was quite equal to any locomotive of its class that had been built up to that period in Philadelphia, and orders came to the makers from several sources for others of the same kind.

In 1836 Henry R. Campbell, of Philadelphia, "in order to distribute the weight of the engine upon the rails more completely," patented the duplication of the driving-wheels, placing one pair behind and one pair in front of the fire-box, using the swivelling truck in front of Baldwin and others.

Mr. Campbell subsequently made an engine after his patent, which was tried on the Philadelphia and Germantown Railroad, and, although not a decided success, it was a great step in the direction in which improvement was most needed. Its principal defect consisted in its having no good means of equalizing the weight on the driving-wheels so as to meet the various undulations in the track.

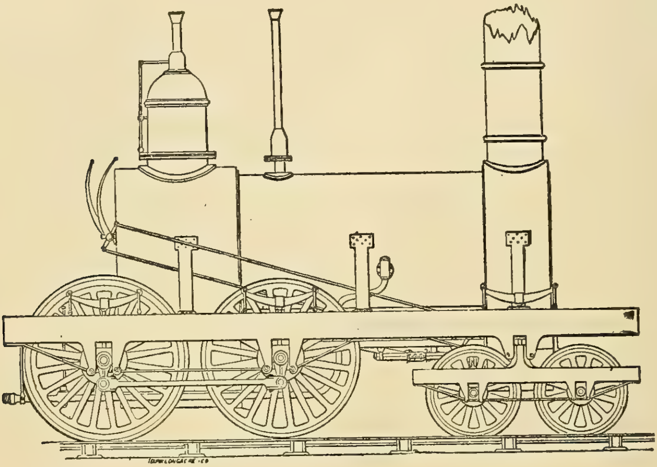
To remedy the defects in the Baldwin, Campbell and Norris engines Garrett & Eastwick (soon thereafter changing their firm to Garrett, Eastwick & Co., Joseph Harrison, Jr., becoming the junior partner) commenced in the winter of 1836–7 a new style of locomotive for the Beaver Meadow Railroad Company.

Adopting the Campbell plan of running gear, they aimed at making a much heavier engine for freight purposes than had yet been used. This could be only rendered possible on the slight roads of the country at that time by a better distribution of the weight upon the rails.

In the first of the improved engines made by Garrett & Eastwick for the Beaver Meadow Railroad Mr. Andrew M. Eastwick introduced an important improvement in the Campbell eight-wheel engine, for which he obtained a patent in 1836. This improvement consisted in the introduction under the rear end of the main frame of a separate frame in which the two axles were placed, one pair before and one pair behind the fire-box. This separate frame was made rigid in the *Hercules*, the first engine in which it was used, and vibrated upon its centre vertically, and being held together firmly at the ends, both sides at all times moved in the same plane, thus only accommodating the undulations in the track in a perfect manner, when the irregularities were on both rails alike. The

weight of the engine rested upon the centre of the sides of this separate frame through the intervention of a strong spring above the main frame, the separate frame being held in place by a pedestal bolted to the main frame, the centres of the separate frame vibrating upon a journal sliding vertically in this pedestal.

Mr. Eastwick's design was, however, somewhat imperfect in not accommodating the weight of the four driving-wheels to the irregular undulations on both tracks. There were other minor improvements in the *Hercules*, one of which was the introduction, for the first time into steam machinery, of the bolted stub-end instead of



HENRY R. CAMPBELL'S FIRST DESIGN FOR AN EIGHT-WHEELED LOCOMOTIVE, 1836.

the old-fashioned and unsafe mode of gib and key for holding the strap on the connecting rods. This device, an idea of Mr. Harrison's, is now universally used in the connecting rods of the locomotive engine.

Doubts were expressed by some, and amongst them not a few engine-builders, that the *Hercules*, weighing about *fifteen tons*, would prove too heavy—that this engine would not turn curves or go into switches without trouble, etc., etc., but Eastwick & Harrison had good friends in Captain Matthew C. Jenkins, a director, and Mr. A. Pardee, the chief-engineer of the Beaver Meadow Railroad. They had committed themselves to this new style of locomotive

and were not disposed to see it fail for lack of a fair trial. They had no cause to regret their confidence in after years. At the time the *Hercules* was placed upon the Beaver Meadow Railroad this road had a flat rail, but five-eighths of an inch thick and two and a half inches wide, laid upon continuous string-pieces of wood with mud-sills underneath.

The *Hercules*, when put in operation on the Beaver Meadow Railroad, proved a great success and led to other orders for the same class of engine. This division of the weight on more points of the road, and its more perfect equalization thereon, seemed at the time, as it has proved since, to have been the commencement of a new era in the history of the locomotive. To remedy the defect incident to Mr. Eastwick's plan, as before mentioned, in these early eight-wheel engines, an improvement was patented in 1838 by Joseph Harrison, Jr., the junior partner of the firm of Eastwick & Harrison.

Mr. Harrison's patent showed many ways of carrying out the principle of his improvement, but the one preferred consisted in placing the driving axle bearings in pedestals, in the usual manner, bolted to the main frame, and by the use of a compensating lever above the main frame, vibrating on its centre, at the point of attachment to the main frame, the ends of this lever resting on the axle-boxes by means of pins passing through the frame. These levers vibrated on each side of the engine separately, and thus met all the unevenness in both rails within a certain prescribed limit, which was governed by the play of the axle-boxes in the pedestals.

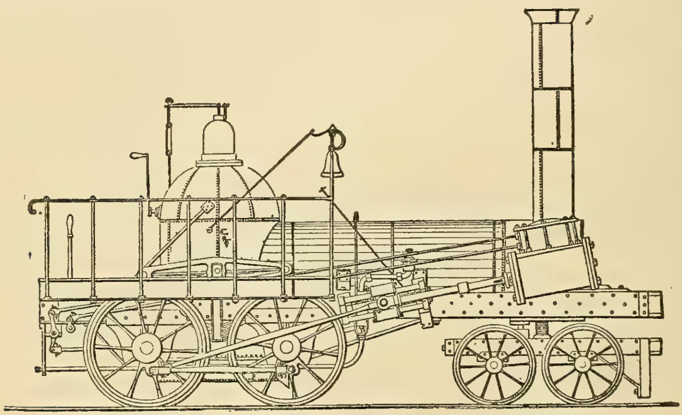
This arrangement of Mr. Harrison's was simpler, lighter and cheaper than the one that had preceded it and was used in all the eight-wheel engines built by Eastwick & Harrison after the second one.

In all engines now built in this country or in Europe, with more than six wheels, this device of Mr. Harrison is used in one or other of the different ways indicated in his patent. Mr. Harrison's patent included an improvement in the forward truck, making it flexible, so that it would accommodate itself to irregular undulations on both rails.

The engineers and manufacturers of this period did not at once fully understand the significance of the innovation so successfully carried out by Eastwick & Harrison. They clung to the older idea

that one pair of driving-wheels was quite sufficient whether placed before the fire-box or behind, nor did they fairly adopt the new system until after its value had been fully demonstrated by several years of trial.

In the summer of 1839 Eastwick & Harrison received an order from the Philadelphia and Reading Railroad Company, through the chief-engineer, Mr. Moncure Robinson, for a freight engine that had peculiar points. This engine was designed generally upon the *Hercules* plan, but it was stipulated in the contract that the whole weight should be *eleven tons* gross, with *nine tons* on the four driving wheels. It was also stipulated that it should burn anthracite coal in a horizontal tubular boiler.



"HERCULES,"

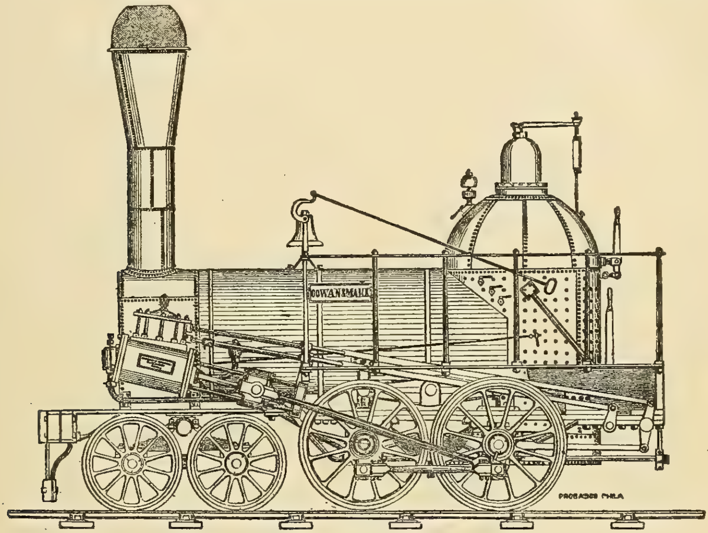
Garrett & Eastwick's first eight-wheeled Locomotive, 1837, as arranged with "Harrison" equalizing levers.

To distribute the nine tons on the driving-wheels the rear axle was placed *under* the fire-box and somewhat in advance of its central line, instead of being behind the fire-box, as in the *Hercules*. This arrangement of the rear axle permitted nine tons of the whole weight of the engine to rest on the four driving-wheels. The boiler was of the Bury type, and the fire-box had the then unprecedented length, outside, of five feet. The tubes, two inches in diameter and only five feet long, were more numerous than usual and filled the cylinder part of the boiler almost to the top. Cylinders 12½ inches in diameter, 18-inch stroke, using no cut-off; driving-wheels

42 inches. The Gurney draft-box was used with many exhaust jets instead of one or two large ones.

It is believed, that in this engine was used, for the first time, the steam-jet for exciting the fire when standing. The engine here described, called, when finished, the *Gowan & Marx*, after a London banking firm, excited much attention in the railroad world by its great tractive power, compared with its whole weight.

On one of its trips (February 20, 1840) it drew a train of *one hundred and one* four-wheeled loaded cars from Reading to Phila-



FREIGHT ENGINE "GOWAN & MARX," 1839.

Designed and built by Eastwick & Harrison, Philadelphia, for the Philadelphia and Reading Railroad, 1839. Slightly varied from the original.

delphia, at an average speed of 9.82+ miles per hour, nine miles of the road being a continuous level. The gross load on this occasion was 423 tons, not including the engine and tender, which, if the weight of the tender is counted, equalled *forty times* the weight of the engine.

See *Journal of Franklin Institute*, 1840, vol. 25, page 99, Report of G. N. Nicols, Superintendent Philadelphia and Reading Railroad, which closes as follows: "The above performance of an eleven-ton engine is believed to excel any on record in this or any other country." It may be doubted whether it has been excelled since.

How strangely this feat of the *Gowan & Marx* compares with the trials on the Liverpool and Manchester Railroad in October, 1829, but ten years before, when all that was required of the competing locomotives was that they should draw about *three times* their own weight, tender included, on a level track, five miles long, especially prepared for the trial. The great success of the *Gowan & Marx* induced the Philadelphia and Reading Railroad Company to duplicate the plan of this engine in ten engines subsequently built at Lowell, Mass.

In 1840 the *Gowan & Marx* attracted the particular attention of the Russian engineers, Colonels Melnikoff and Krafft, who had been commissioned by the Emperor Nicholas to examine into and report upon the various systems of railroads and railroad machinery then in operation in this country and in Europe.

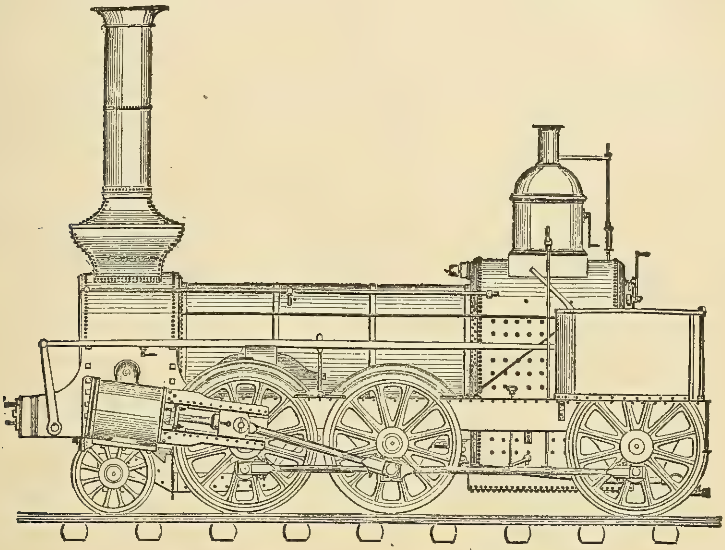
The result of their examination was favorable to the American system, and when the engineers above named made their report on the construction of a railroad from St. Petersburg to Moscow, an engine upon the plan of the *Gowan & Marx* was recommended as best adapted to the purposes of this first great line of railroad in the Empire of Russia, and Eastwick & Harrison were requested to visit St. Petersburg with the view of making a contract for building the locomotives and other machinery for the road.

Mr. Harrison went to St. Petersburg in the spring of 1843, and in connection with Mr. Thomas Winans, of Baltimore, a contract was concluded with the government of Russia, at the close of the same year, for building 162 locomotives, and iron trucks for 2500 freight-cars. Mr. Eastwick joined Mr. Harrison and Mr. Winans at St. Petersburg in 1844.

Eastwick & Harrison closed their establishment in Philadelphia in 1844, removing a portion of their tools and instruments to St. Petersburg, and there, under the firm of Harrison, Winans & Eastwick, completed, at the Alexandroffsky Head Mechanical Works, the work for which they had contracted. When the work was commenced under the contract of Harrison, Winans & Eastwick with the Russian government, Joseph Harrison, Jr., designed and had built under his own supervision, at St. Petersburg, the first machine, it is believed, that was ever made for boring out the holes for right-angled crank-pins in the driving-wheels of locomotive engines. This right-angled boring-machine, on precisely the same

principle as devised by Mr. Harrison, has since become indispensable in every locomotive establishment. The same idea was partially put in use as early as 1838, when the second eight-wheel engine *Beaver* was built by Garrett & Eastwick for the Beaver Meadow Railroad.

The first contract with the Russian government was closed in 1851, at which time a second contract was entered into, by two



HARRISON, WINANS & EASTWICK'S FREIGHT ENGINE.

Built at St. Petersburg, Russia, for the St. Petersburg & Moscow Railroad, 1844.

members of the firm, for the repairs to the rolling stock of the St. Petersburg and Moscow Railroad, which continued until 1862.

Note.—We are indebted for the above lengthy and valuable extract to a work published in Philadelphia, 1872 (Geo. Gebbie), written by Joseph Harrison, Jr.: "The Locomotive and Philadelphia's Share in its Early Improvement." Mr. Harrison was one of the ablest and most successful mechanics that America has ever produced: he was a gentleman of great good taste, eminent for his broad views and liberal patriotic aid in all good works. He was born in Philadelphia in 1810 and died there 1875.

[Having in a brief manner brought the history of the steam-engine in both Europe and America forward to 1842, we find the subject suddenly expand beyond all hopes of even keeping a fair report of the various establishments started for the manufacture of boilers and steam-engines of every description. Not only every country has many private shops and factories, but nearly every railroad company has its own machine-shops. In order to bring the story of progress forward till near the present day, we will as briefly as possible notice the progress of locomotive engine building at the Baldwin Locomotive Works, Philadelphia, which, being the largest establishment of its kind in the world, may be considered a representative establishment.]

In 1840 Mr. Baldwin received an order, through August Belmont, Esq., of New York, for a locomotive for Austria, and had nearly completed one which was calculated to do the work required when he learned that only sixty pounds pressure of steam was admissible, whereas his engine was designed to use steam at one hundred pounds and over. He accordingly constructed another, meeting this requirement, and shipped it in the following year. This engine, it may be noted, had a kind of link-motion, agreeably to the specification received, and was the first of his make upon which the link was introduced.

Mr. Baldwin's patent of December 31, 1840, covering his geared engine, embraced several other devices, as follows:

1. A method of operating a fan, or blowing-wheel, for the purpose of blowing the fire. The fan was to be placed under the footboard, and driven by the friction of a grooved pulley in contact with the flange of the driving-wheel.

2. The substitution of a metallic stuffing, consisting of wire, for the hemp, wool, or other material which had been employed in stuffing-boxes.

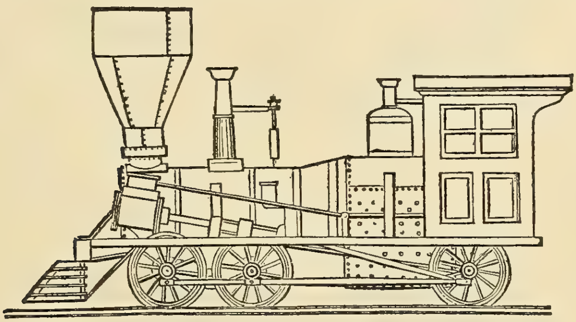
3. The placing of the springs of the engine-truck so as to obviate the evil of the locking of the wheels when the truck-frame vibrates from the centre-pin vertically. Spiral as well as semi-elliptic springs, placed at each end of the truck-frame, were specified. The spiral spring is described as received in two cups—one above and one below. The cups were connected together at their centres by a pin upon one and a socket in the other, so that the cups could approach toward or recede from each other and still preserve their parallelism.

4. An improvement in the manner of constructing the iron frames of locomotives, by making the pedestals in one piece with, and constituting part of, the frames.

5. The employment of spiral springs in connection with cylindrical pedestals and boxes. A single spiral was at first used, but not proving sufficiently strong, a combination or nest of spirals curving alternately in opposite directions was afterward employed. Each spiral had its bearing in a spiral recess in the pedestal.

In the specification of this patent a change in the method of making cylindrical pedestals and boxes is noted. Instead of boring and turning them in a lathe, they were cast to the required shape in chills. This method of construction was used for a time, but eventually a return was made to the original plan, as giving a more accurate job.

In 1842 Mr. Baldwin constructed, under an arrangement with Mr. Ross Winans, three locomotives for the Western Railroad of Massa-

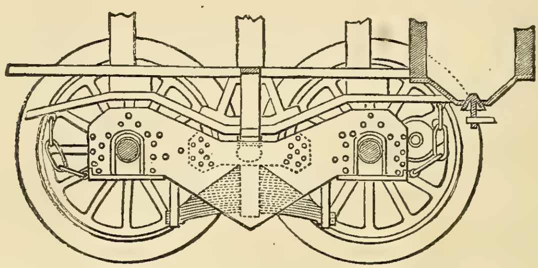


BALDWIN SIX-WHEELS-CONNECTED ENGINE, 1842.

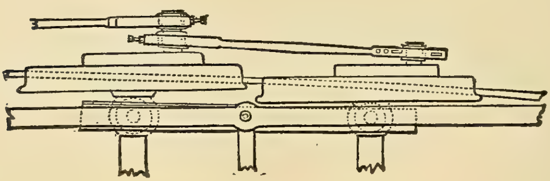
chusetts, on a plan which had been designed by that gentleman for freight traffic. These machines had upright boilers and horizontal cylinders, which worked cranks on a shaft bearing cog-wheels engaging with other cog-wheels on an intermediate shaft. This latter shaft had cranks coupled to four driving-wheels on each side. These engines were constructed to burn anthracite coal. Their peculiarly uncouth appearance earned for them the name of "crabs," and they were but short-lived in service.

But to return to the progress of Mr. Baldwin's locomotive practice. The geared engine had not proved a success. It was unsatisfactory, as well to its designer as to the railroad community. The problem of utilizing more or all of the weight of the engine for adhesion remained, in Mr. Baldwin's view, yet to be solved. The plan of coupling four or six wheels had long before been adopted in

England, but on the short curves prevalent on American railroads he felt that something more was necessary. The wheels must not only be coupled, but at the same time must be free to adapt themselves to a curve. These two conditions were apparently incompatible, and to reconcile these inconsistencies was the task which Mr. Baldwin set himself to accomplish. He undertook it, too, at a time when his business had fallen off greatly and he was involved in the most serious financial embarrassments. The problem was constantly before him, and at length, during a sleepless night, its solution flashed across his mind. The plan so long sought for, and



BALDWIN FLEXIBLE-BEAM TRUCK, 1842—ELEVATION.



HALF PLAN.

which, subsequently, more than any other of his improvements or inventions, contributed to the foundation of his fortune, was his well-known six-wheels-connected locomotive with the four front driving-wheels combined in a flexible truck. For this machine Mr. Baldwin secured a patent, August 25, 1842. Its principal characteristic features are now matters of history, but they deserve here a brief mention. The engine was on six wheels, all connected. The rear wheels were placed rigidly in the frames, usually behind the fire-box with inside bearings. The cylinders were inclined, and with outside connections. The four remaining wheels had inside journals running in boxes held by two wide and deep wrought-iron beams, one

on each side. These beams were unconnected, and entirely independent of each other. The pedestals formed in them were bored out cylindrically, and into them cylindrical boxes, as patented by him in 1835, were fitted. The engine frame on each side was directly over the beam, and a spherical pin, running down from the frame, bore in a socket in the beam midway between the two axles. It will thus be seen that each side-beam independently could turn horizontally or vertically under the spherical pin, and the cylindrical boxes could also turn in the pedestals. Hence, in passing a curve, the middle pair of drivers could move laterally in one direction—say to the right—while the front pair could move in the opposite direction, or to the left; the two axles all the while remaining parallel to each other and to the rear driving-axle. The operation of these beams was, therefore, like that of the parallel-ruler. On a straight line the two beams and the two axles formed a rectangle; on curves a parallelogram, the angles varying with the degree of curvature. The coupling-rods were made with cylindrical brasses, thus forming ball-and-socket joints, to enable them to accommodate themselves to the lateral movements of the wheels.

The first engine of the new plan was finished early in December, 1842, being one of fourteen engines constructed in that year, and was sent to the Georgia Railroad, on the order of Mr. J. Edgar Thomson, then Chief Engineer and Superintendent of that line. It weighed twelve tons, and drew, besides its own weight, two hundred and fifty tons up a grade of thirty-six feet to the mile.

Other orders soon followed. The new machine was received generally with great favor. The loads hauled by it exceeded anything so far known in American railroad practice, and sagacious managers hailed it as a means of largely reducing operating expenses. On the Central Railroad, of Georgia, one of these twelve-ton engines drew nineteen eight-wheeled cars, with seven hundred and fifty bales of cotton, each bale weighing four hundred and fifty pounds, over maximum grades of thirty feet per mile, and the manager of the road declared that it could readily take one thousand bales. On the Philadelphia and Reading Railroad a similar engine of eighteen tons weight drew one hundred and fifty loaded cars (total weight of cars and lading one thousand one hundred and thirty tons) from Schuylkill Haven to Philadelphia, at a speed of seven miles per hour. The regular load was one hundred loaded

cars, which were hauled at a speed of from twelve to fifteen miles per hour on a level.

But the flexible-beam truck also enabled Mr. Baldwin to supply an engine with four driving-wheels connected. Other builders were making engines with four driving-wheels and a four-wheeled truck, of the present American standard type. To compete with this design, Mr. Baldwin modified his six-wheels-connected engine by connecting only two out of the three pairs of wheels, making the forward wheels of smaller diameter as leading wheels, but combining them with the front driving-wheels in a flexible-beam truck. The first engine on this plan was sent to the Erie and Kalamazoo Railroad, in October, 1843, and gave great satisfaction. The superintendent of the road was enthusiastic in its praise, and wrote to Mr. Baldwin that he doubted "if anything could be got up which would answer the business of the road so well." One was also sent to the Utica and Schenectady Railroad a few weeks later, of which the superintendent remarked that "it worked beautifully, and there were not wagons enough to give it a full load." In this plan the leading wheels were usually made thirty-six and the driving-wheels fifty-four inches in diameter.

This machine of course came in competition with the eight-wheeled engine having four driving-wheels, and Mr. Baldwin claimed for his plan a decided superiority. In each case about two-thirds of the total weight was carried on the four driving-wheels, and Mr. Baldwin maintained that his engine, having only six instead of eight wheels, was simpler and more effective.

At about this period Mr. Baldwin's attention was called by Mr. Levi Bissell to an "Air Spring" which the latter had devised, and which it was imagined was destined to be a cheap, effective, and perpetual spring. The device consisted of a small cylinder placed above the frame over the axle-box, and having a piston fitted air-tight into it. The piston-rod was to bear on the axle-box, and the proper quantity of air was to be pumped into the cylinder above the piston, and the cylinder then hermetically closed. The piston had a leather packing which was to be kept moist by some fluid (molasses was proposed) previously introduced into the cylinder. Mr. Baldwin at first proposed to equalize the weight between two pairs of drivers by connecting two air-springs on each side by a pipe, the use of an equalizing beam being covered by Messrs. Eastwick &

Harrison's patent. The air-springs were found, however, not to work practically, and were never applied. It may be added that a model of an equalizing air-spring was exhibited by Mr. Joseph Harrison, Jr., at the Franklin Institute, in 1838 or 1839.

With the introduction of the new machine, business began at once to revive and the tide of prosperity turned once more in Mr. Baldwin's favor. Twelve engines were constructed in 1843, all but four of them of the new pattern; twenty-two engines in 1844, all of the new pattern; and twenty-seven in 1845. Three of this number were of the old type, with one pair of driving-wheels, but from that time forward the old pattern with the single pair of driving-wheels disappeared from the practice of the establishment, save occasionally for exceptional purposes.

In 1842 the partnership with Mr. Vail was dissolved, and Mr. Asa Whitney, who had been superintendent of the Mohawk and Hudson Railroad, became a partner with Mr. Baldwin, and the firm continued as Baldwin & Whitney until 1846, when the latter withdrew to engage in the manufacture of car-wheels, establishing the firm of A. Whitney & Sons, Philadelphia.

Mr. Whitney brought to the firm a railroad experience and thorough business talent. He introduced a system in many details of the management of the business, which Mr. Baldwin, whose mind was devoted more exclusively to mechanical subjects, had failed to establish or wholly ignored. The method at present in use in the establishment, of giving to each class of locomotives a distinctive designation, composed of a number and a letter, originated very shortly after Mr. Whitney's connection with the business. For the purpose of representing the different designs, sheets with engravings of locomotives were employed. The sheet showing the engine with one pair of driving-wheels was marked B; that with two pairs, C; that with three, D; and that with four, E. Taking its rise from this circumstance, it became customary to designate as B engines those with one pair of driving-wheels; as C engines, those with two pairs; as D engines, those with three pairs; and as E engines, those with four pairs. Shortly afterwards a number, indicating the weight in gross tons, was added. Thus, the 12 D engine was one with three pairs of driving-wheels, and weighing twelve tons; the 12 C, an engine of same weight, but with only four wheels connected. A modification of this method of designating the several plans and sizes is still in use, and is explained elsewhere.

It will be observed that the classification as thus established began with the B engines. The letter A was reserved for an engine intended to run at very high speeds, and so designed that the driving-wheels should make two revolutions for each reciprocation of the pistons. This was to be accomplished by means of gearing. The general plan of the engine was determined in Mr. Baldwin's mind, but was never carried into execution.

The period under consideration was marked also by the introduction of the French & Baird stack, which proved at once to be one of the most successful spark-arresters thus far employed, and which was for years used almost exclusively wherever, as on the cotton-carrying railroads of the South, a thoroughly effective spark-arrester was required. This stack was introduced by Mr. Baird, then a foreman in the works, who purchased the patent-right of what had been known as the Grimes stack, and combined with it some of the features of the stack made by Mr. Richard French, then master mechanic of the Germantown Railroad, together with certain improvements of his own. The cone over the straight inside pipe was made with volute flanges on its under side, which gave a rotary motion to the sparks. Around the cone was a casing about six inches smaller in diameter than the outside stack. Apertures were cut in the sides of this casing, through which the sparks in their rotary motion were discharged, and thus fell to the bottom of the space between the straight inside pipe and the outside stack. The opening in the top of the stack was fitted with a series of V-shaped iron circles perforated with numerous holes, thus presenting an enlarged area, through which the smoke escaped. The patent-right for this stack was subsequently sold to Messrs. Radley & Hunter, and its essential principle is still used in the Radley & Hunter stack as at present made.

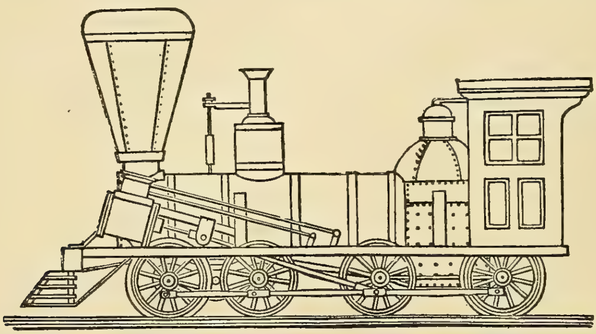
In 1845 Mr. Baldwin built three locomotives for the Royal Railroad Committee of Würtemberg. They were of fifteen tons weight, on six wheels, four of them being sixty inches in diameter and coupled. The front driving-wheels were combined by the flexible beams into a truck with the smaller leading wheels. The cylinders were inclined and outside, and the connecting-rods took hold of a half-crank axle back of the fire-box. It was specified that these engines should have the link-motion which had shortly before been introduced in England by the Stephensons. Mr. Baldwin accord-

ingly applied a link of a peculiar character to suit his own ideas of the device. The link was made solid, and of a truncated V-section, and the block was grooved so as to fit and slide on the outside of the link.

During the year 1845 another important feature in locomotive construction—the cut-off valve—was added to Mr. Baldwin's practice. Up to that time the valve-motion had been the two eccentrics, with the single flat hook for each cylinder. Since 1841 Mr. Baldwin had contemplated the addition of some device allowing the steam to be used expansively, and he now added the "half-stroke cut-off." In this device the steam-chest was separated by a horizontal plate into an upper and a lower compartment. In the upper compartment a valve, worked by a separate eccentric, and having a single opening, admitted steam through a port in this plate to the lower steam-chamber. The valve-rod of the upper valve terminated in a notch or hook, which engaged with the upper arm of its rock-shaft. When thus working, it acted as a cut-off at a fixed part of the stroke, determined by the setting of the eccentric. This was usually at half the stroke. When it was desired to dispense with the cut-off and work steam for the full stroke, the hook of the valve-rod was lifted from the pin on the upper arm of the rock-shaft by a lever worked from the foot-board, and the valve-rod was held in a notched rest fastened to the side of the boiler. This left the opening through the upper valve and the port in the partition-plate open for the free passage of steam throughout the whole stroke. The first application of the half-stroke cut-off was made on the engine *Champlain* (20 D), built for the Philadelphia and Reading Railroad Company, in 1845. It at once became the practice to apply the cut-off on all passenger engines, while the six- and eight-wheels-connected freight engines were, with a few exceptions, built for a time longer with the single valve admitting steam for the full stroke.

After building, during the years 1843, 1844, and 1845, ten four-wheels-connected engines on the plan above described, viz., six wheels in all, the leading wheels and the front driving-wheels being combined into a truck by the flexible beams, Mr. Baldwin finally adopted the present design of four driving-wheels and a four-wheeled truck. Some of his customers who were favorable to the latter plan had ordered such machines of other builders, and Colonel Gadsden, President of the South Carolina Railroad Company,

called on him in 1845 to build for that line some passenger engines of this pattern. He accordingly bought the patent-right for this plan of engine of Mr. H. R. Campbell, and for the equalizing beams used between the driving-wheels, of Messrs. Eastwick & Harrison, and delivered to the South Carolina Railroad Company, in December, 1845, his first eight-wheeled engine with four driving-wheels and a four-wheeled truck. This machine had cylinders thirteen and three-quarters by eighteen, and driving-wheels sixty inches in diameter, with the springs between them arranged as equalizers. Its weight was fifteen tons. It had the half-crank axle, the cylinders being inside the frame but outside the smoke-box. The inside-connected engine, counterweighting being as yet unknown, was admitted to be steadier in running, and hence more suitable for passenger



BALDWIN EIGHT-WHEELS-CONNECTED "C" ENGINE, 1846.

service. With the completion of the first eight-wheeled "C" engine Mr. Baldwin's feelings underwent a revulsion in favor of this plan, and his partiality for it became as great as had been his antipathy before. Commenting on the machine, he recorded himself as "more pleased with its appearance and action than any engine he had turned out." In addition to the three engines of this description for the South Carolina Railroad Company, a duplicate was sent to the Camden and Amboy Railroad Company, and a similar but lighter one to the Wilmington and Baltimore Railroad Company, shortly afterwards. The engine for the Camden and Amboy Railroad Company, and perhaps the others, had the half-stroke cut-off.

From that time forward all of his four-wheels-connected machines were built on this plan, and the six-wheeled "C" engine was abandoned, except in the case of one built for the Philadelphia, German-

town and Norristown Railroad Company in 1846, and this was afterwards rebuilt into a six-wheels-connected machine. Three methods of carrying out the general design were, however, subsequently followed. At first the half-crank was used; then horizontal cylinders inclosed in the chimney-seat and working a full-crank axle, which form of construction had been practiced at the Lowell Works; and eventually, outside cylinders with outside connections.

Forty-two engines were completed in 1846, and thirty-nine in 1847. The only novelty to be noted among them was the engine *M. G. Bright*, built for operating the inclined plane on the Madison and Indianapolis Railroad. The rise of this incline was one in seventeen, from the bank of the Ohio river at Madison. The engine had eight wheels, forty-two inches in diameter, connected, and worked in the usual manner by outside inclined cylinders, fifteen and one-half inches diameter by twenty inches stroke. A second pair of cylinders, seventeen inches in diameter with eighteen inches stroke of piston, was placed vertically over the boiler, midway between the furnace and smoke-arch. The connecting-rods worked by these cylinders connected with cranks on a shaft under the boiler. This shaft carried a single cog-wheel at its centre, and this cog-wheel engaged with another of about twice its diameter on a second shaft adjacent to it and in the same plane. The cog-wheel on this latter shaft worked in a rack-rail placed in the centre of the track. The shaft itself had its bearings in the lower ends of two vertical rods, one on each side of the boiler, and these rods were united over the boiler by a horizontal bar which was connected by means of a bent lever and connecting-rod to the piston worked by a small horizontal cylinder placed on top of the boiler. By means of this cylinder, the yoke carrying the shaft and cog-wheel could be depressed and held down so as to engage the cogs with the rack-rail, or raised out of the way when only the ordinary driving-wheels were required. This device was designed by Mr. Andrew Cathcart, Master Mechanic of the Madison and Indianapolis Railroad. A similar machine, the *John Brough*, for the same plane, was built by Mr. Baldwin in 1850. The incline was worked with a rack-rail and these engines until it was finally abandoned and a line with easier gradients substituted.

The use of iron tubes in freight engines grew in favor, and in

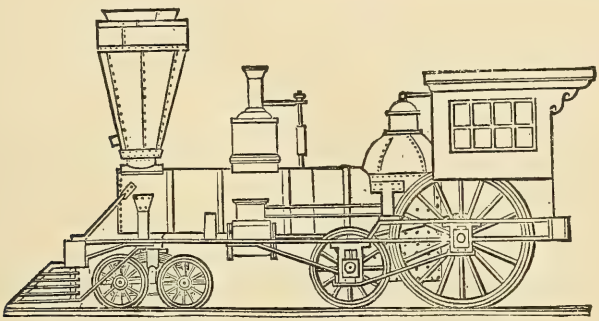
October, 1847, Mr. Baldwin noted that he was fitting his flues with copper ends, "for riveting to the boiler."

The subject of burning coal continued to engage much attention, but the use of anthracite had not as yet been generally successful. In October, 1847, the Baltimore and Ohio Railroad Company advertised for proposals for four engines to burn Cumberland coal, and the order was taken and filled by Mr. Baldwin with four of his eight-wheels-connected machines. These engines had a heater on top of the boiler for heating the feed-water, and a grate with a rocking-bar in the centre, having fingers on each side which interlocked with projections on fixed bars, one in front and one behind. The rocking-bar was operated from the foot-board. This appears to have been the first instance of the use of a rocking-grate in the practice of these works.

The year 1848 showed a falling off in business, and only twenty engines were turned out. In the following year, however, there was a rapid recovery, and the production of the works increased to thirty, followed by thirty-seven in 1850, and fifty in 1851. These engines, with a few exceptions, were confined to three patterns, the eight-wheeled four-coupled engine, from twelve to nineteen tons in weight, for passengers and freight, and the six- and eight-wheels-connected engine, for freight exclusively, the six-wheeled machine weighing from twelve to seventeen tons, and the eight-wheeled from eighteen to twenty-seven tons. The wheels of these six- and eight-wheels-connected machines were made generally forty-two, with occasional variations up to forty-eight, inches in diameter.

The exceptions referred to in the practice of these years were the fast passenger engines built by Mr. Baldwin during this period. Early in 1848 the Vermont Central Railroad was approaching completion, and Governor Paine, the President of the company, conceived the idea that the passenger service on the road required locomotives capable of running at very high velocities. Mr. Baldwin at once undertook to construct for that company a locomotive which could run with a passenger train at a speed of sixty miles per hour. The work was begun early in 1848, and in March of that year Mr. Baldwin filed a caveat for his design. The engine was completed in 1849, and was named the *Governor Paine*. It had one pair of driving-wheels, six and a half feet in diameter, placed back of the fire-box. Another pair of wheels, but smaller and uncon-

nected, was placed directly in front of the fire-box, and a four-wheeled truck carried the front of the engine. The cylinders were seventeen and a quarter inches diameter and twenty inches stroke, and were placed horizontally between the frames and the boiler, at about the middle of the waist. The connecting-rods took hold of "half-cranks" inside of the driving-wheels. The object of placing the cylinders at the middle of the boiler was to lessen or obviate the lateral motion of the engine, produced when the cylinders were attached to the smoke-arch. The bearings on the two rear axles were so contrived that, by means of a lever, a part of the weight of the engine usually carried on the wheels in front of the fire-box could be transferred to the driving-axle. The *Governor Paine* was used for several years on the Vermont Central Railroad, and then



BALDWIN FAST PASSENGER ENGINE, 1848.

rebuilt into a four-coupled machine. During its career it was stated by the officers of the road that it could be started from a state of rest and run a mile in forty-three seconds. Three engines on the same plan, but with cylinders fourteen by twenty, and six-feet driving-wheels, the *Mifflin*, *Blair*, and *Indiana*, were also built for the Pennsylvania Railroad Company in 1849. They weighed each about forty-seven thousand pounds, distributed as follows: eighteen thousand on driving-wheels, fourteen thousand on the pair of wheels in front of the fire-box, and fifteen thousand on the truck. By applying the lever, the weight on the driving-wheels could be increased to about twenty-four thousand pounds, the weight on the wheels in front of the fire-box being correspondingly reduced. A speed of four miles in three minutes is recorded for them, and upon

one occasion President Taylor was taken in a special train over the road by one of these machines at a speed of sixty miles an hour. One other engine of this pattern, the *Susquehanna*, was built for the Hudson River Railroad Company in 1850. Its cylinders were fifteen inches diameter by twenty inches stroke, and driving-wheels six feet in diameter. All these engines, however, were short-lived, and died young, of insufficient adhesion.

Eight engines with four driving-wheels connected and half-crank axles were built for the New York and Erie Railroad Company in 1849, with seventeen by twenty-inch cylinders; one-half of the number with six-feet and the rest with five-feet driving-wheels. These machines were among the last on which the half-crank axle was used. Thereafter, outside-connected engines were constructed almost exclusively.

In May, 1848, Mr. Baldwin filed a caveat for a four-cylinder locomotive, but never carried the design into execution. The first instance of the use of steel axles in the practice of the establishment occurred during the same year—a set being placed as an experiment under an engine constructed for the Pennsylvania Railroad Company. In 1850 the old form of dome boiler, which had characterized the Baldwin engine since 1834, was abandoned, and the wagon-top form substituted.

The business in 1851 had reached the full capacity of the shop, and the next year marked the completion of about an equal number of engines (forty-nine). Contracts for work extended a year ahead, and, to meet the demand, the facilities in the various departments were increased, and resulted in the construction of sixty engines in 1853, and sixty-two in 1854.

At the beginning of the latter year, Mr. Matthew Baird, who had been connected with the works since 1836 as one of its foremen, entered into partnership with Mr. Baldwin, and the style of the firm was made M. W. Baldwin & Co.

The only novelty in the general plan of engines during this period was the addition of the ten-wheeled engine to the patterns of the establishment. The success of Mr. Baldwin's engines with all six or eight wheels connected, and the two front pairs combined by the parallel beams into a flexible truck, had been so marked that it was natural that he should oppose any other plan for freight service. The ten-wheeled engine, with six driving-wheels connected, had,

however, now become a competitor. This plan of engine was first patented by Septimus Norris, of Philadelphia, in 1846, and the original design was apparently to produce an engine which should have equal tractive power with the Baldwin six-wheels-connected machine. This the Norris patent sought to accomplish by proposing an engine with six driving-wheels connected, and so disposed as to carry substantially the whole weight, the forward driving-wheels being in advance of the centre of gravity of the engine, and the truck only serving as a guide, the front of the engine being connected with it by a pivot-pin, but without a bearing on the centre-plate. Mr. Norris's first engine on this plan was tried in April, 1847, and was found not to pass curves so readily as was expected. As the truck carried little or no weight, it would not keep the track. The New York and Erie Railroad Company, of which John Brandt was then Master Mechanic, shortly afterwards adopted the ten-wheeled engine, modified in plan so as to carry a part of the weight on the truck. Mr. Baldwin filled an order for this company, in 1850, of four eight-wheels-connected engines, and in making the contract he agreed to substitute a truck for the front pair of wheels if desired after trial. This, however, he was not called upon to do.

In February, 1852, Mr. J. Edgar Thomson, President of the Pennsylvania Railroad Company, invited proposals for a number of freight locomotives of fifty-six thousand pounds weight each. They were to be adapted to burn bituminous coal, and to have six wheels connected and a truck in front, which might be either of two or four wheels. Mr. Baldwin secured the contract, and built twelve engines of the prescribed dimensions, viz., cylinders eighteen by twenty-two; driving-wheels forty-four inches in diameter, with chilled tires. Several of these engines were constructed with a single pair of truck-wheels in front of the driving-wheels, but back of the cylinders. It was found, however, after the engines were put in service, that the two truck-wheels carried eighteen thousand or nineteen thousand pounds, and this was objected to by the company as too great a weight to be carried on a single pair of wheels. On the rest of the engines of the order, therefore, a four-wheeled truck in front was employed.

The ten-wheeled engine thereafter assumed a place in the Baldwin classification. In 1855–56, two of twenty-seven tons weight, nineteen by twenty-two cylinders, forty-eight inches driving-wheels,

were built for the Portage Railroad, and three for the Pennsylvania Railroad. In 1855, '56, and '57, fourteen of the same dimensions were built for the Cleveland and Pittsburg Railroad; four for the Pittsburg, Fort Wayne and Chicago Railroad; and one for the Marietta and Cincinnati Railroad. In 1858 and '59, one was constructed for the South Carolina Railroad, of the same size, and six lighter ten wheelers, with cylinders fifteen and a half by twenty-two, and four-feet driving-wheels, and two with cylinders sixteen by twenty-two, and four-feet driving-wheels, were sent out to railroads in Cuba.

It was some years—not until after 1860, however—before this pattern of engine wholly superseded in Mr. Baldwin's practice the old plan of freight engine on six or eight wheels, all connected.

On three locomotives—the *Clinton*, *Athens*, and *Sparta*—completed for the Central Railroad of Georgia in July, 1852, the driving-boxes were made with a slot or cavity in the line of the vertical bearing on the journal. The object was to produce a more uniform distribution of the wear over the entire surface of the bearing. This was the first instance in which this device, which has since come into general use, was employed in the Works, and the boxes were so made by direction of Mr. Charles Whiting, then Master Mechanic of the Central Railroad of Georgia. He subsequently informed Mr. Baldwin that this method of fitting up driving-boxes had been in use on the road for several years previous to his connection with the company. As this device was subsequently made the subject of a patent by Mr. David Matthew, these facts may not be without interest.

In 1853, Mr. Charles Ellet, Chief Engineer of the Virginia Central Railroad, laid a temporary track across the Blue Ridge, at Rock Fish Gap, for use during the construction of a tunnel through the mountain. This track was twelve thousand five hundred feet in length on the eastern slope, ascending in that distance six hundred and ten feet, or at the average rate of one in twenty and a half feet. The maximum grade was calculated for two hundred and ninety-six feet per mile, and prevailed for half a mile. It was found, however, in fact, that the grade in places exceeded three hundred feet per mile. The shortest radius of curvature was two hundred and thirty-eight feet. On the western slope, which was ten thousand six hundred and fifty feet in length, the maximum grade was two hundred

and eighty feet per mile, and the ruling radius of curvature three hundred feet. This track was worked by two of the Baldwin six-wheels-connected flexible-beam truck locomotives constructed in 1853–54.

But the period now under consideration was marked by another, and a most important, step in the progress of American locomotive practice. We refer to the introduction of the link-motion. Although this device was first employed by William T. James, of New York, in 1832, and eleven years later by the Stephensons, in England, and was by them applied thenceforward on their engines, it was not until 1849 that it was adopted in this country. In that year Mr. Thomas Rogers, of the Rogers Locomotive and Machine Company, introduced it in his practice. Other builders, however, strenuously resisted the innovation, and none more so than Mr. Baldwin. The theoretical objections which confessedly apply to the device, but which practically have been proved to be unimportant, were urged from the first by Mr. Baldwin as arguments against its use. The strong claim of the advocates of the link-motion, that it gave a means of cutting off steam at any point of the stroke, could not be gainsaid, and this was admitted to be a consideration of the first importance. This very circumstance undoubtedly turned Mr. Baldwin's attention to the subject of methods for cutting off steam, and one of the first results was his "Variable Cut-off," patented April 27, 1852. This device consisted of two valves, the upper sliding upon the lower, and worked by an eccentric and rock-shaft in the usual manner. The lower valve fitted steam-tight to the sides of the steam-chest and the under surface of the upper valve. When the piston reached each end of its stroke, the full pressure of steam from the boiler was admitted around the upper valve, and transferred the lower valve instantaneously from one end of the steam-chest to the other. The openings through the two valves were so arranged that steam was admitted to the cylinder only for a part of the stroke. The effect was, therefore, to cut off steam at a given point, and to open the induction and exhaust ports substantially at the same instant and to their full extent. The exhaust port, in addition, remained fully open while the induction port was gradually closing, and after it had entirely closed. Although this device was never put in use, it may be noted in passing that it contained substantially the principle of the steam-pump, as since patented and constructed.

Early in 1853 Mr. Baldwin abandoned the half-stroke cut-off,

previously described, and which he had been using since 1845, and adopted the variable cut-off, which was already employed by other builders. One of his letters, written in January, 1853, states his position, as follows:

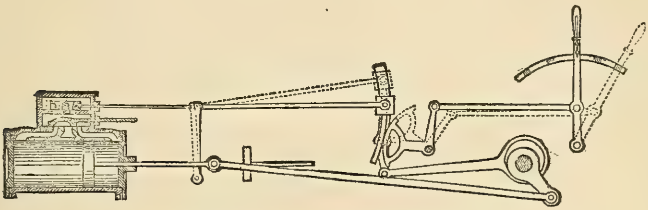
> "I shall put on an improvement in the shape of a variable cut-off, which can be operated by the engineer while the machine is running, and which will cut off anywhere from six to twelve inches, according to the load and amount of steam wanted, and this without the link-motion, which I could never be entirely satisfied with. I still have the independent cut-off, and the additional machinery to make it variable will be simple and not liable to be deranged."

This form of cut-off was a separate valve, sliding on a partition plate between it and the main steam-valve, and worked by an independent eccentric and rock-shaft. The upper arm of the rock-shaft was curved so as to form a radius-arm, on which a sliding-block, forming the termination of the upper valve-rod, could be adjusted and held at varying distances from the axis, thus producing a variable travel of the upper valve. This device did not give an absolutely perfect cut-off, as it was not operative in backward gear, but when running forward it would cut off with great accuracy at any point of the stroke, was quick in its movement, and economical in the consumption of fuel.

After a short experience with this arrangement of the cut-off, the partition plate was omitted, and the upper valve was made to slide directly on the lower. This was eventually found objectionable, however, as the lower valve would soon cut a hollow in the valve-face. Several unsuccessful attempts were made to remedy this defect by making the lower valve of brass, with long bearings, and making the valve-face of the cylinder of hardened steel; finally, however, the plan of one valve on the other was abandoned and a recourse was again had to an interposed partition plate, as in the original half-stroke cut-off.

Mr. Baldwin did not adopt this form of cut-off without some modification of his own, and the modification in this instance consisted of a peculiar device, patented September 13, 1853, for raising and lowering the block on the radius-arm. A quadrant was placed so that its circumference bore nearly against a curved arm projecting down from the sliding-block, and which curved in the reverse direction from the quadrant. Two steel straps side by side were interposed between the quadrant and this curved arm. One of the straps

was connected to the lower end of the quadrant and the upper end of the curved arm; the other to the upper end of the quadrant and the lower end of the curved arm. The effect was the same as if the quadrant and arm geared into each other in any position by teeth, and theoretically the block was kept steady in whatever position



VARIABLE CUT-OFF ADJUSTMENT.

placed on the radius-arm of the rock-shaft. This was the object sought to be accomplished, and was stated in the specification of the patent as follows:

"The principle of varying the cut-off by means of a vibrating arm and sliding pivot-block has long been known, but the contrivances for changing the position of the block upon the arm have been very defective. The radius of motion of the link by which the sliding-block is changed on the arm, and the radius of motion of that part of the vibrating arm on which the block is placed, have, in this kind of valve-gear, as heretofore constructed, been different, which produced a continual rubbing of the sliding-block upon the arm while the arm is vibrating; and as the block for the greater part of the time occupies one position on the arm, and only has to be moved toward either extremity occasionally, that part of the arm on which the block is most used soon becomes so worn that the block is loose, and jars."

This method of varying the cut-off was first applied on the engine *Belle*, delivered to the Pennsylvania Railroad Company, December 6, 1854, and thereafter was for some time employed by Mr. Baldwin. It was found, however, in practice that the steel straps would stretch sufficiently to allow them to buckle and break, and hence they were soon abandoned, and chains substituted between the quadrant and curved arm of the sliding-block. These chains in turn proved little better, as they lengthened, allowing lost motion, or broke altogether, so that eventually the quadrant was wholly abandoned, and recourse was finally had to the lever and link for raising and lowering the sliding-block. As thus arranged, the cut-off was substantially what was known as the " Cuyahoga Cut-

off," as introduced by Mr. Ethan Rogers, of the Cuyahoga Works, Cleveland, Ohio, except that Mr. Baldwin used a partition plate between the upper and the lower valve.

But while Mr. Baldwin, in common with many other builders, was thus resolutely opposing the link-motion, it was nevertheless rapidly gaining favor with railroad managers. Engineers and master mechanics were everywhere learning to admire its simplicity, and were manifesting an enthusiastic preference for engines so constructed. At length, therefore, he was forced to succumb: and the link was applied to the *Pennsylvania*, one of two engines completed for the Central Railroad of Georgia, in February, 1854. The other engine of the order, the *New Hampshire*, had the variable cut-off, and Mr. Baldwin, while yielding to the demand in the former engine, was undoubtedly sanguine that the working of the latter would demonstrate the inferiority of the new device. In this, however, he was disappointed, for in the following year the same company ordered three more engines, on which they specified the link-motion. In 1856 seventeen engines for nine different companies had this form of valve gear, and its use was thus incorporated in his practice. It was not, however, until 1857 that he was induced to adopt it exclusively.

February 14, 1854, Mr. Baldwin and Mr. David Clark, Master Mechanic of the Mine Hill Railroad, took out conjointly a patent for a feed-water heater, placed at the base of a locomotive chimney, and consisting of one large vertical flue, surrounded by a number of smaller ones. The exhaust steam was discharged from the nozzles through the large central flue, creating a draft of the products of combustion through the smaller surrounding flues. The pumps forced the feed-water into the chamber around these flues, whence it passed to the boiler by a pipe from the back of the stack. This heater was applied on several engines for the Mine Hill Railroad, and on a few for other roads; but its use was exceptional, and lasted only for a year or two.

In December of the same year Mr. Baldwin filed a caveat for a variable exhaust, operated automatically, by the pressure of steam, so as to close when the pressure was lowest in the boiler, and open with the increase of pressure. The device was never put in service.

The use of coal, both bituminous and anthracite, as a fuel for locomotives, had by this time become a practical success. The

economical combustion of bituminous coal, however, engaged considerable attention. It was felt that much remained to be accomplished in consuming the smoke and deriving the maximum of useful effect from the fuel. Mr. Baird, who was now associated with Mr. Baldwin in the management of the business, made this matter a subject of careful study and investigation. An experiment was con ducted under his direction, by placing a sheet-iron deflector in the fire-box of an engine on the Germantown and Norristown Railroad. The success of the trial was such as to show conclusively that a more complete combustion resulted. As, however, a deflector formed by a single plate of iron would soon be destroyed by the action of the fire, Mr. Baird proposed to use a water-leg projecting upward and backward from the front of the fire-box under the flues. Drawings and a model of the device were prepared, with a view of patenting it, but subsequently the intention was abandoned, Mr. Baird concluding that a fire-brick arch as a deflector to accomplish the same object was preferable. This was accordingly tried on two locomotives built for the Pennsylvania Railroad Company in 1854, and was found so valuable an appliance that its use was at once established, and it was put on a number of engines built for railroads in Cuba and elsewhere. For several years the fire-bricks were supported on side plugs; but in 1858, in the *Media*, built for the West Chester and Philadelphia Railroad Company, water-pipes extending from the crown obliquely downward and curving to the sides of the fire-box at the bottom were successfully used for the purpose.

The adoption of the link-motion may be regarded as the dividing line between the present and the early and transitional stage of locomotive practice. Changes since that event have been principally in matters of detail, but it is the gradual perfection of these details which has made the locomotive the symmetrical, efficient, and wonderfully complete piece of mechanism it is to-day. In perfecting these minutiæ, the Baldwin Locomotive works has borne its part, and it only remains to state briefly its contributions in this direction.

The production of the establishment during the six years from 1855 to 1860, inclusive, was as follows; forty-seven engines in 1855; fifty-nine in 1856; sixty-six in 1857; thirty-three in 1858; seventy in 1859; and eighty-three in 1860. The greater number of these were of the ordinary type, four wheels coupled, and a four-wheeled truck, and varying in weight from fifteen ton engines, with

cylinders twelve by twenty-two, to twenty-seven ton engines, with cylinders sixteen by twenty-four. A few ten-wheeled engines were built, as has been previously noted, and the remainder were the Baldwin flexible-truck six- and eight-wheels-connected engines. The demand for these, however, was now rapidly falling off, the ten-wheeled and heavy "C" engines taking their place, and by 1859 they ceased to be built, save in exceptional cases, as for some foreign roads, from which orders for this pattern were still occasionally received.

A few novelties characterizing the engines of this period may be mentioned. Several engines built in 1855 had cross-flues placed in the fire-box, under the crown, in order to increase the heating surface. This feature, however, was found impracticable, and was soon abandoned. The intense heat to which the flues were exposed converted the water contained in them into highly super-heated steam, which would force its way out through the water around the fire-box with violent ebullitions. Four engines were built for the Pennsylvania Railroad Company, in 1856–57, with straight boilers and two domes. The *Delano* grate, by means of which the coal was forced into the fire-box from below, was applied on four ten-wheeled engines for the Cleveland and Pittsburg Railroad in 1857. In 1859 several engines were built with the form of boiler introduced on the Cumberland Valley Railroad in 1851 by Mr. A. F. Smith, and which consisted of a combustion-chamber in the waist of the boiler, next the fire-box. This form of boiler was for some years thereafter largely used in engines for soft coal. It was at first constructed with the "water-leg," which was a vertical water-space, connecting the top and bottom sheets of the combustion-chamber, but eventually this feature was omitted, and an unobstructed combustion-chamber employed. Several engines were built for the Philadelphia, Wilmington and Baltimore Railroad Company in 1859, and thereafter, with the *Dimpfel* boiler, in which the tubes contain water, and starting downward from the crown-sheet, are curved to the horizontal, and terminate in a narrow water-space next the smoke-box. The whole waist of the boiler, therefore, forms a combustion chamber, and the heat and gases, after passing for their whole length along and around the tubes, emerge into the lower part of the smoke-box.

In 1860 an engine was built for the Mine Hill Railroad, with a boiler of a peculiar form. The top sheets sloped upward from both

ends towards the centre, thus making a raised part or hump in the centre. The engine was designed to work on heavy grades, and the object sought by Mr. Wilder, the Superintendent of the Mine Hill Railroad, was to have the water always at the same height in the space from which steam was drawn, whether going up or down grade.

All these experiments are indicative of the interest then prevailing upon the subject of coal-burning. The result of experience and study had meantime satisfied Mr. Baldwin that to burn soft coal successfully required no peculiar devices; that the ordinary form of boiler, with plain fire-box, was right, with perhaps the addition of a fire-brick deflector; and that the secret of the economical and successful use of coal was in the mode of firing, rather than in a different form of furnace.

The year 1861 witnessed a marked falling off in the production. The breaking out of the civil war at first unsettled business, and by many it was thought that railroad traffic would be so largely reduced that the demand for locomotives must cease altogether. A large number of hands were discharged from the works, and only forty locomotives were turned out during the year. It was even seriously contemplated to turn the resources of the establishment to the manufacture of shot and shell, and other munitions of war, the belief being entertained that the building of locomotives would have to be altogether suspended. So far, however, was this from being the case, that, after the first excitement had subsided, it was found that the demand for transportation by the general government, and by the branches of trade and production stimulated by the war, was likely to tax the carrying capacity of the principal Northern railroads to the fullest extent. The government itself became a large purchaser of locomotives, and it is noticeable, as indicating the increase of travel and freight transportation, that heavier machines than had ever before been built became the rule. Seventy-five engines were sent from the works in 1862; ninety-six in 1863; one hundred and thirty in 1864; and one hundred and fifteen in 1865. During two years of this period, from May, 1862, to June, 1864, thirty-three engines were built for the United States Military Railroads. The demand from the various coal-carrying roads in Pennsylvania and vicinity was particularly active, and large numbers of ten-wheeled engines, and of the heaviest eight-wheeled four-coupled engines,

were built. Of the latter class, the majority were with fifteen- and sixteen-inch cylinders, and of the former, seventeen- and eighteen-inch cylinders.

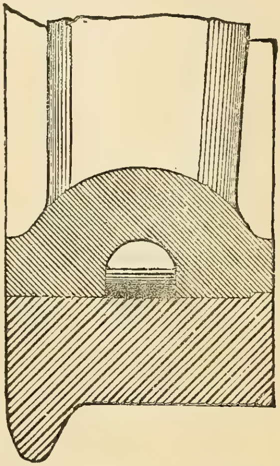
The introduction of several important features in construction marks this period. Early in 1861, four eighteen-inch cylinder freight locomotives, with six coupled wheels, fifty-two inches in diameter, and a Bissell pony-truck with radius-bar in front, were sent to the Louisville and Nashville Railroad Company. This was the first instance of the use of the Bissell truck in the Baldwin Works. These engines, however, were not of the regular *Mogul* type, as they were only modifications of the ten-wheeler, the drivers retaining the same position, well back, and a pair of pony-wheels on the Bissell plan taking the place of the ordinary four-wheeled truck. Other engines of the same pattern, but with eighteen and one-half inch cylinders, were built in 1862–63, for the same company, and for the Dom Pedro II. Railway of Brazil.

The introduction of steel in locomotive-construction was a distinguishing feature of the period. Steel tires were first used in the works in 1862, on some engines for the Dom Pedro II. Railway of South America. Their general adoption on American Railroads followed slowly. No tires of this material were then made in this country, and it was objected to their use that, as it took from sixty to ninety days to import them, an engine, in case of a breakage of one of its tires, might be laid up useless for several months. To obviate this objection M. W. Baldwin & Co. imported five hundred steel tires, most of which were kept in stock, from which to fill orders. The steel tires as first used in 1862 on the locomotives for the Dom Pedro Segundo Railway were made with a "shoulder" at one edge of the internal periphery, and were shrunk on the wheel-centres.

Steel fire-boxes were first built for some engines for the Pennsylvania Railroad Company in 1861. English steel of a high temper was used, and at the first attempt the fire-boxes cracked in fitting them in the boilers, and it became necessary to take them out and substitute copper. American homogeneous cast-steel was then tried on engines 231 and 232, completed for the Pennsylvania Railroad in January, 1862, and it was found to work successfully. The fire-boxes of nearly all engines thereafter built for that road were of this material, and in 1866 its use for the purpose became general.

It may be added that while all steel sheets for fire-boxes or boilers are required to be thoroughly annealed before delivery, those which are flanged or worked in the process of boiler construction are a second time annealed before riveting.

Another feature of construction gradually adopted was the placing of the cylinders horizontally. This was first done in the case of an outside-connected engine, the *Ocmulgee*, which was sent to the Southwestern Railroad Company of Georgia, in January, 1858. This engine had a square smoke-box, and the cylinders were bolted horizontally to its sides. The plan of casting the cylinder and half-saddle in one piece and fitting it to the round smoke-box was introduced by Mr. Baldwin, and grew naturally out of his original method of construction. Mr. Baldwin was the first American builder to use an outside cylinder, and he made it for his early engines with a circular flange cast to it, by which it could be bolted to the boiler. The cylinders were gradually brought lower, and at a less angle, and the flanges prolonged and enlarged. In 1852 three six-wheels-connected engines, for the Mine Hill Railroad Company, were built with the cylinder flanges brought around under the smoke-box until they nearly met, the space between them being filled with a spark-box. This was practically equivalent to making the cylinder and half-saddle in one casting. Subsequently, on other engines on which the spark-box was not used, the half-saddles were cast so as almost to meet under the smoke-box, and, after the cylinders were adjusted in position, wedges were fitted in the interstices and the saddles bolted together. It was finally discovered that the faces of the two half-saddles might be planed and finished so that they could be bolted together and bring the cylinders accurately in position, thus avoiding the troublesome and tedious job of adjusting them by chipping and fitting to the boiler and frames. With this method of construction the cylinders were placed at a less and less angle, until at length the truck-wheels were spread sufficiently, on all new or modified classes



HORIZONTAL CYLINDERS.

of locomotives in the Baldwin list, to admit of the cylinders being hung horizontally, as is the present almost universal American practice. By the year 1865 horizontal cylinders were made in all cases where the patterns would allow it. The advantages of this arrangement are manifestly in the interest of simplicity and economy, as the cylinders are thus rights or lefts, indiscriminately, and a single pattern answers for either side.

A distinguishing feature in the method of construction which characterizes these works is the extensive use of a system of standard gauges and templets, to which all work admitting of this process is required to be made. The importance of this arrangement, in securing absolute uniformity of essential parts in all engines of the same class, is manifest, and with the increased production since 1861 it became a necessity as well as a decided advantage.

Thus had been developed and perfected the various essential details of existing locomotive practice when Mr. Baldwin died, September 7, 1866. He had been permitted, in a life of unusual activity and energy, to witness the rise and wonderful increase of a material interest which had become the distinguishing feature of the century. He had done much, by his own mechanical skill and inventive genius, to contribute to the development of that interest. His name was as "familiar as household words" wherever on the American continent the locomotive had penetrated.

To do right, absolutely and unreservedly, in all his relations with men, was an instinctive rule of his nature. His heroic struggle to meet every dollar of his liabilities, principal and interest, after his failure, consequent upon the general financial crash in 1837, constitutes a chapter of personal self-denial and determined effort which is seldom paralleled in the annals of commercial experience. When most men would have felt that an equitable compromise with creditors was all that could be demanded in view of the general financial embarrassment, Mr. Baldwin insisted upon paying all claims in full, and succeeded in doing so only after nearly five years of unremitting industry, close economy, and absolute personal sacrifices. As a philanthropist and a sincere and earnest Christian, zealous in every good work, his memory is cherished by many to whom his contributions to locomotive improvement are comparatively unknown. From the earliest years of his business life the practice of systematic benevolence was made a duty and a pleasure. His liberality con-

stantly increased with his means. Indeed, he would unhesitatingly give his notes, in large sums, for charitable purposes when money was absolutely wanted to carry on his business. Apart from the thousands which he expended in private charities, and of which, of course, little can be known, Philadelphia contains many monuments of his munificence.

After the death of Mr. Baldwin the business was reorganized, in 1867, under the title of "The Baldwin Locomotive Works," M. Baird & Co., Proprietors. Messrs. George Burnham and Charles T. Parry, who had been connected with the establishment from an early period, the former in charge of the finances, and the latter as General Superintendent, were associated with Mr. Baird in the copartnership. Three years later, Messrs. Edward H. Williams, William P. Henszey, and Edward Longstreth became members of the firm. Mr. Williams had been connected with railway management on various lines since 1850. Mr. Henszey had been Mechanical Engineer, and Mr. Longstreth the General Superintendent of the works for several years previously.

The production of the Baldwin Locomotive Works from 1866 to 1871, both years inclusive, was as follows:

1866, one hundred and eighteen locomotives.
1867, one hundred and twenty-seven "
1868, one hundred and twenty-four "
1869, two hundred and thirty-five "
1870, two hundred and eighty "
1871, three hundred and thirty-one "

In July, 1866, the engine *Consolidation* was built for the Lehigh Valley Railroad, on the plan and specification furnished by Mr. Alexander Mitchell, Master Mechanic of the Mahanoy Division of that railroad. This engine was intended for working the Mahanoy plane, which rises at the rate of one hundred and thirty-three feet per mile. The *Consolidation* had cylinders twenty by twenty-four, four pairs of wheels connected, forty-eight inches in diameter, and a Bissell pony-truck in front, equalized with the front driving-wheels. The weight of the engine, in working order, was ninety thousand pounds, of which all but about ten thousand pounds was on the driving-wheels. This engine has constituted the first of a

class to which it has given its name, and *Consolidation* engines have since been constructed for a large number of railways, not only in the United States, but in Mexico, Brazil, and Australia.

A class of engines known as *Moguls*, with three pairs of wheels connected and a swinging pony-truck in front equalized with the forward driving-wheels, took its rise in the practice of this establishment from the *E. A. Douglas*, built for the Thomas Iron Company, in 1867. Several sizes of *Moguls* have been built, but principally with cylinders sixteen to nineteen inches in diameter, and twenty-two or twenty-four inches stroke, and with driving-wheels from forty-four to fifty-seven inches in diameter. This plan of engine has rapidly grown in favor for freight service on heavy grades or where maximum loads are to be moved, and has been adopted by several leading lines. Utilizing, as it does, nearly the entire weight of the engine for adhesion, the main and back pairs of driving-wheels being equalized together, as also the front driving-wheels and the pony-wheels, and the construction of the engine with swing-truck and one pair of driving-wheels without flanges allowing it to pass short curves without difficulty, the *Mogul* is generally accepted as a type of engine especially adapted to the economical working of heavy freight traffic.

In 1867, on a number of eight-wheeled four-coupled engines for the Pennsylvania Railroad, the four-wheeled swing-bolster-truck was first applied, and thereafter a large number of engines have been so constructed. The two-wheeled or "pony-truck" has been built both on the Bissell plan, with double inclined slides, and with the ordinary swing-bolster, and in both cases with the radius-bar pivoting from a point about four feet back from the centre of the truck. The four-wheeled truck has been made with swinging or sliding bolster, and both with and without the radius-bar. Of the engines above referred to as the first on which the swing-bolster-truck was applied, four were for express passenger service, with driving-wheels sixty-seven inches in diameter, and cylinders seventeen by twenty-four. One of them, placed on the road September 9, 1867, was in constant service until May 14, 1871, without ever being off its wheels for repairs, making a total mileage of one hundred and fifty-three thousand two hundred and eighty miles. All of these engines have their driving-wheels spread eight and one-half feet between centres.

Steel flues were first used in three ten-wheeled freight engines, Numbers 211, 338, and 368, completed for the Pennsylvania Raïlroad in August, 1868. Flues of the same material have also been used in a number of engines for South American railroads. Experience with tubes of this metal, however, has not yet been sufficiently extended to show whether they give any advantages commensurate with their increased cost over iron.

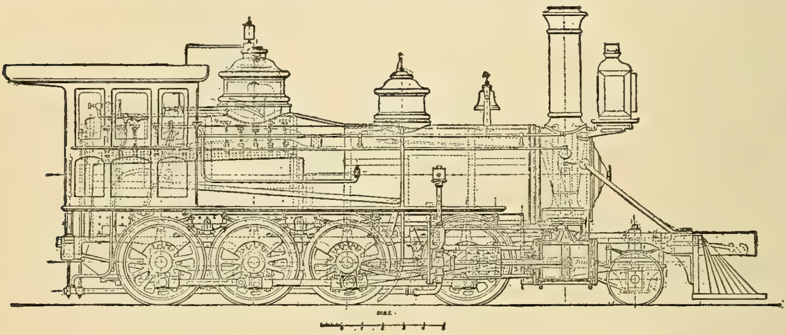
Steel boilers were first made in 1868 for locomotives for the Pennsylvania Railroad Company, and the use of this material for the barrels of boilers as well as for the fire-boxes has continued to some extent. Steel plates somewhat thinner than if of iron have been generally used, but at the same time giving an equal or greater tensile strength. The thoroughly homogeneous character of the steel boiler-plate made in this country recommends it strongly for the purpose.

In 1854 four engines for the Pennsylvania Railroad Company, the *Tiger*, *Leopard*, *Hornet* and *Wasp*, were built with straight boilers and two domes each, and in 1866 this method of construction was revived. Since that date the practice of the establishment has included both the wagon-top boiler with single dome, and the straight boiler with one or two domes. When the straight boiler is used the waist is made about two inches larger in diameter than that of the wagon-top form. About equal space for water and steam is thus given in either case, and, as the number of flues is the same in both forms, more room for the circulation of water between the flues is afforded in the straight boiler, on account of its larger diameter, than in the wagon-top shape. Where the straight boiler is used with two domes the throttle-valve is placed in the forward dome.

In 1868, a locomotive of three and a half feet gauge was constructed for the Averill Coal and Oil Company, of West Virginia. This was the first narrow-gauge locomotive in the practice of the works.

In 1869 three locomotives of the same gauge were constructed for the Uniao Valenciana Railway of Brazil, and were the first narrow-gauge locomotives constructed at these works for general passenger and freight traffic. In the following year the Denver and Rio Grande Railway, of Colorado, was projected on the three-feet gauge, and the first locomotives for the line were designed and built in

1871. Two classes, for passenger and freight respectively, were constructed. The former were six-wheeled, four wheels coupled forty inches in diameter, nine by sixteen cylinders, and weighed each, loaded, about twenty-five thousand pounds. The latter were eight-wheeled, six wheels coupled thirty-six inches in diameter, eleven by sixteen cylinders, and weighed each, loaded, about thirty-five thousand pounds. Each had a swinging-truck of a single pair of wheels in front of the cylinders. The latter type has been maintained for freight service on most narrow-gauge lines, but principally of larger sizes, engines as heavy as fifty thousand pounds having been turned out. The former type for passenger service was found to be too small and to be unsteady on the track, owing to its comparatively short wheel-base. It was therefore abandoned, and the



FREIGHT LOCOMOTIVE, "CONSOLIDATION" TYPE.

ordinary "American" pattern, eight-wheeled, four-coupled, substituted. Following the engines for the Denver and Rio Grande Railway, others for other narrow-gauge lines were called for, and the manufacture of this description of rolling stock soon assumed importance. From 1868 to 1870, inclusive, eleven narrow-gauge locomotives were included in the product. The number of narrow-gauge locomotives built in succeeding years has been as follows: 1871, thirty-two; 1872, nineteen; 1873, twenty-nine; 1874, forty-four; 1875, thirty-six; 1876, fifty one; 1877, sixty-five; 1878, seventy-five; 1879, seventy-eight.

The *Consolidation* type, as first introduced for the four feet eight and one-half inches gauge in 1866, was adapted to the three-feet gauge in 1873. In 1877 a locomotive on this plan, weighing in working order about sixty thousand pounds, with cylinders fifteen

by twenty, was built for working the Garland extension of the Denver and Rio Grande Railway, which crosses the Rocky Mountains with maximum grades of two hundred and eleven feet per mile, and minimum curves of thirty degrees. The performance of this locomotive, the *Alamosa*, is given in the following extract from a letter from the then General Superintendent of that railway:

"DENVER, COL., Aug. 31, 1877.

"On the 29th inst. I telegraphed you from Veta Pass—Sangre de Cristo Mountains—that engine *Alamosa* had just hauled from Garland to the Summit one baggage car and seven coaches, containing one hundred and sixty passengers. Yesterday I received your reply asking for particulars, etc.

"My estimate of the weight was eighty-five net tons, stretched over a distance of three hundred and sixty feet, or including the engine, of four hundred and five feet.

"The occasion of this sized train was an excursion from Denver to Garland and return. The night before, in going over from La Veta, we had over two hundred passengers, but it was 8 P. M., and, fearing a slippery rail, I put on engine No. 19 as a pusher, although the engineer of the *Alamosa* said he could haul the train, and I believe he could have done so. The engine and train took up a few feet more than the half circle at 'Mule Shore,' where the radius is one hundred and ninety-three feet. The engine worked splendidly, and moved up the two hundred and eleven feet grades and around the thirty degree curves seemingly with as much ease as our passenger engines on seventy-five feet grades with three coaches and baggage cars.

"The *Alamosa* hauls regularly eight loaded cars and caboose, about one hundred net tons; length of train about two hundred and thirty feet.

"The distance from Garland to Veta Pass is fourteen and one-quarter miles, and the time is one hour and twenty minutes. Respectfully yours,

(Signed) "W. W. BORST, *Sup't.*"

In addition to narrow-gauge locomotives for the United States, this branch of the product has included a large number of one-metre gauge locomotives for Brazil, three-feet gauge locomotives for Cuba, Mexico, and Peru, and three and one-half feet gauge stock for Costa Rica, Nicaragua, Canada, and Australia.

Locomotives for single-rail railroads were built in 1878 and early in 1879, adapted respectively to the systems of General Roy Stone and Mr. W. W. Riley.

In 1870, in some locomotives for the Kansas Pacific Railway, the steel tires were shrunk on without being secured by bolts or rivets in any form, and since that time this method of putting on tires has been the rule.

In 1871 forty locomotives were constructed for the Ohio and Mississippi Railway, the gauge of which was changed from five feet six

inches to four feet eight and one-half inches. The entire lot of forty locomotives was completed and delivered in about twelve weeks. The gauge of the road was changed on July 4th, and the forty locomotives went at once into service in operating the line on the standard gauge.

The product of the works, which had been steadily increasing for some years in sympathy with the requirements of the numerous new railroads which were constructing, reached three hundred and thirty-one locomotives in 1871, and four hundred and twenty-two in 1872. Orders for ninety locomotives for the Northern Pacific Railroad were entered during 1870–71, and for one hundred and twenty-four for the Pennsylvania Railroad during 1872–73, and mostly executed during those years. A contract was also made during 1872 with the Veronej-Rostoff Railway of Russia for ten locomotives to burn Russian anthracite coal. Six were *Moguls*, with cylinders nineteen by twenty-four, and driving-wheels four and one-half feet diameter; and four were passenger locomotives, "American" pattern, with cylinders seventeen by twenty-four, and driving-wheels five and one-half feet diameter. Nine "American" pattern locomotives, fifteen by twenty-four cylinders, and five-feet driving-wheels, were also constructed in 1872–73 for the Hango-Hyvinge Railway of Finland.

Early in 1873 Mr. Baird sold his interest in the works to his five partners, and a new firm was formed under the style of Burnham, Parry, Williams & Co., dating from January 1st of that year. Mr. John H. Converse, who had been connected with the works since 1870, became a member of the new firm. The product of this year was four hundred and thirty-seven locomotives, the greatest in the history of the business. During a part of the year ten locomotives per week were turned out. Nearly three thousand men were employed. Forty-five locomotives for the Grand Trunk Railway of Canada were built in August, September, and October, 1873, and all were delivered in five weeks after shipment of the first. As in the case of the Ohio and Mississippi Railway, previously noted, these were to meet the requirements of a change of gauge from five and one-half feet to four feet eight and one-half inches. Two *Consolidation* locomotives were sent in September, 1873, to the Mexican Railway. These had cylinders twenty by twenty-four; driving-wheels forty-nine inches in diameter; and weighed, loaded,

about 95,000 pounds each, of which about 82,000 pounds were on the driving-wheels. These engines hauled in their trial trips, without working to their full capacity, five loaded cars up the four per cent. grades of the Mexican Railway. In November, 1873, under circumstances of especial urgency, a small locomotive for the Meier Iron Company of St. Louis was wholly made from the raw material in sixteen working days.

The financial difficulties which prevailed throughout the United States, beginning in September, 1873, and affecting chiefly the railroad interests and all branches of manufacture connected therewith, have operated of course to curtail the production of locomotives since that period. Hence, only two hundred and five locomotives were built in 1874, and one hundred and thirty in 1875. Among these may be enumerated two sample locomotives for burning anthracite coal (one passenger, sixteen by twenty-four cylinders, and one *Mogul* freight, eighteen by twenty-four cylinders) for the Technical Department of the Russian Government; also, twelve *Mogul* freight locomotives, nineteen by twenty-four cylinders, for the Charkoff Nicolaieff Railroad of Russia. A small locomotive to work by compressed air, for drawing street cars, was constructed during 1874 for the Compressed Air Locomotive and Street Car Company of Louisville, Ky. It had cylinders seven by twelve, and four wheels coupled, thirty inches in diameter. Another and smaller locomotive to work by compressed air was constructed three years later for the Plymouth Cordage Company of Massachusetts, for service on a track in and about their works. It had cylinders five by ten, four wheels coupled twenty-four inches diameter, weight, seven thousand pounds, and has been successfully employed for the work required.

The year 1876, noted as the year of the Centennial International Exhibition in Philadelphia, brought some increase of business, and two hundred and thirty-two locomotives were constructed. An exhibit consisting of eight locomotives was prepared for this occasion. With the view of illustrating not only different types of American locomotives, but the practice of different railroads, the exhibit consisted chiefly of locomotives constructed to fill orders from various railroad companies of the United States and from the Imperial Government of Brazil. A *Consolidation* locomotive for burning anthracite coal, for the Lehigh Valley Railroad, for which

line the first locomotive of this type was designed and built in 1866; a similar locomotive, to burn bituminous coal, and a passenger locomotive for the same fuel for the Pennsylvania Railroad; a *Mogul* freight locomotive, the *Principe do Grao Para*, for the D. Pedro Segundo Railway of Brazil; and a passenger locomotive (anthracite burner) for the Central Railroad of New Jersey, comprised the larger locomotives contributed by these works to the Exhibition of 1876. To these were added a mine locomotive and two narrow (three feet) gauge locomotives, which were among those used in working the Centennial Narrow-Gauge Railway.

Steel fire-boxes with vertical corrugations in the side sheets were first made by these Works early in 1876, in locomotives for the Central Railroad of New Jersey, and for the Delaware, Lackawanna and Western Railway.

The first American locomotives of New South Wales and Queensland were constructed by the Baldwin Locomotive Works in 1877, and were succeeded by additional orders in 1878 and 1879. Six locomotives of the *Consolidation* type for three and one-half feet gauge were also constructed in the latter year for the Government Railways of New Zealand, and two freight locomotives, six-wheels-connected with forward truck, for the Government of Victoria. Four similar locomotives (ten-wheeled, six-coupled, with sixteen by twenty-four cylinders) were also built during the same year for the Norwegian State Railways.

Forty heavy *Mogul* locomotives (nineteen by twenty-four cylinders, driving-wheels four and one-half feet in diameter) were constructed early in 1878 for two Russian Railways (the Koursk Charkof Azof, and the Orel Griazi). The definite order for these locomotives was only received on the sixteenth of December, 1877, and as all were required to be delivered in Russia by the following May, especial despatch was necessary. The working force was increased from eleven hundred to twenty-three hundred men in about two weeks. The first of the forty engines was erected and tried under steam on January 5th, three weeks after receipt of order, and was finished, ready to dismantle and pack for shipment, one week later. The last engine of this order was completed February 13th. The forty engines were thus constructed in about eight weeks, besides twenty-eight additional engines on other orders, which were constructed wholly or partially and shipped during the same period.

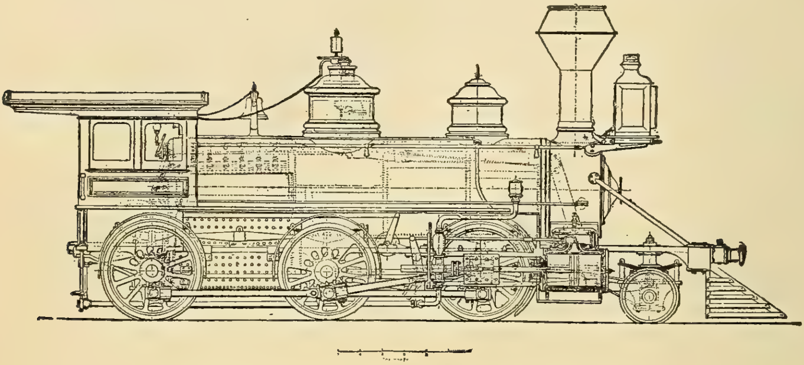
In December, 1878, the heaviest locomotive ever built at these Works was completed for the New Mexico and Southern Pacific Railroad (four feet eight and one-half inches gauge), an extension of the Atchison, Topeka and Santa Fé Railway. It was of the *Consolidation* type, was named *Uncle Dick*, and was of the following general dimensions: Cylinders, twenty by twenty-six inches; driving-wheels, forty-two inches diameter, four pairs connected; truck-wheels, thirty inches diameter, one pair; total wheel-base, twenty-two feet ten inches; wheel-base of flanged driving-wheels, nine feet; capacity of water-tank on boiler, twelve hundred gallons; capacity of water-tank of separate tender, twenty-five hundred gallons; weight of engine in working-order, including water in tank, one hundred and fifteen thousand pounds; weight on driving-wheels, one hundred thousand pounds.

This locomotive was built for working a temporary switchback track (used during the construction of a tunnel) crossing the Rocky Mountains, with maximum grades of six in one hundred. Over these grades the engine hauled its loaded tender (forty-four thousand pounds) and nine loaded cars (each forty-three thousand pounds): total load, exclusive of its own weight, four hundred and thirty-one thousand pounds. On a grade of two per cent. it hauled a train weighing nine hundred and sixty-five thousand pounds, and on one of three and a half per cent., five hundred and seventeen thousand pounds. Curves of sixteen degrees occurred on the switchback track, but not in combination with the six per cent. grades.

The production during the eighteen years from 1872 to 1890 inclusive was as follows:

1872 . . .	422	locomotives.
1873 . . .	437	"
1874 . . .	205	"
1875 . . .	130	"
1876 . . .	232	"
1877 . . .	185	"
1878 . . .	292	"
1879 . . .	398	"
1880 . . .	517	"
1881 . . .	555	"
1882 . .	563	"

1883 . . .	557	locomotives.
1884 . . .	429	"
1885 . . .	242	"
1886 . . .	550	"
1887 . . .	653	"
1888 . . .	737	"
1889 . . .	827	"
1890 . . .	946	"
1891 . . .	1050*	" (estimated).



FREIGHT LOCOMOTIVE, "MOGUL" TYPE.

The year 1891 is marked by the largest production in the history of the Works, and the character of the product reflects the growing demand for larger and more powerful locomotives.

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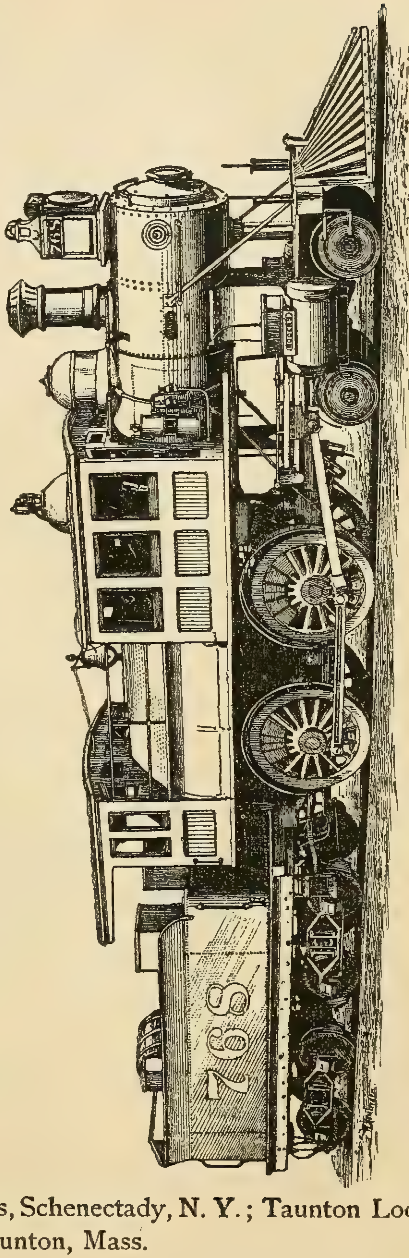
* Compare this with the following: In 1838 the United States Government made a request for statistics of steamboats, locomotives and stationary engines, with the following result:

800 . . .	Steamboats,
350 . . .	Locomotives, and
1861 . . .	Stationary Engines.

Of the latter 383 were in Pennsylvania, and Louisiana came second on the list, 274, which were used chiefly on the sugar plantations. Massachusetts came next with 165; New York, 87; Ohio, 83; the rest distributed among the States. The 800 steamboats were either all coasters or river boats, and although the *Savannah*, built in New York in 1819, had been the first to cross the Atlantic, there was not one classed as an ocean steamer. The largest was a government vessel, *The Natchez*, 860 tons measurement, 300 horse-power. There were 350 locomotives reported, 90 of which were in Pennsylvania; Massachusetts, 37; Virginia, 34; New Jersey, 32; Maryland, 31; New York, 28; South Carolina, 27. No other State had more than 10 owned within its limits.

In order to show the importance of the industry devoted to the manufacture of locomotives, we give a list of twelve first-class establishments throughout the United States engaged in the manufacture, besides the Baldwin Locomotive Works described. Our space forbids our entering into anything like a detail of what is accomplished by these establishments: Brooks Locomotive Works, Dunkirk, N. Y.; Cooke Locomotive & Machine Co., Paterson, N. J.; Hinkley Locomotive Co., Boston, Mass.; Manchester Locomotive Co., Manchester, N. H.; New York Locomotive Works, Rome, N. Y.; Pittsburgh Locomotive & Car Works, Pittsburgh; H. K. Porter & Co., Pittsburgh, Pa.; Rhode Island Locomotive Works, Providence; Richmond Locomotive & Machine Works, Richmond, Va.; Rogers Locomotive & Machine Works, Paterson, N. J.; Schenectady Locomotive Works, Schenectady, N. Y.; Taunton Locomotive Manufacturing Co., Taunton, Mass.



WOOTTEN EXPRESS PASSENGER LOCOMOTIVE, UNION PACIFIC RAILWAY.
Built by the Rogers Locomotive Works, Paterson, N. J.

THE WOOTTEN FIRE-BOX.—One of the latest novelties in locomotive

building has been achieved in rather an indirect manner by Mr. John E. Wootten, formerly Manager of the Philadelphia and Reading Railroad Company. It had occurred to Mr. Wootten that the enormous amount of slack or refuse coal, which is to be found around all coal mines, might possibly be utilized in locomotive fire-boxes, where the opportunity of an enormous draught is possible. He therefore patented a fire-box with a very large surface, indeed, so large that, whereas the fire-box in general use presents a surface of about twenty-six square feet between the wheels, Mr. Wootten, by lifting his fire-box above the wheels, was able to utilize a fire-box with about seventy-five square feet surface. There is a fire-brick arch or division, which is a very essential point in the design of the Wootten fire-box, and gives much of the success of the engines in getting the necessary draught for burning fine coal or slack. Besides the advantage that it gives of utilizing what was formerly worthless waste coal, these engines make steam freely, and haul the heavy express trains of the Union Pacific at a higher rate of speed than has ever before been attained on that road. The coal used is taken from the mines owned by the railroad, and is bituminous, though light, in its character. It is, however, successfully burned without any sparks, a result, of course, due to the enormous grate area, while the heat radiated from the arch fire-bricks or wall maintains an even temperature and insures complete combustion. The large area of the grate prevents any appreciable lifting of the fire, and the small pieces of live coal that are sucked up by the blast are burned on their way to the flues, owing to the high temperature of the brick arch. In the Wootten express engine, of which we give an illustration, it will be seen from the prospective view of the engine and tender, that the engines have two cabs, and thus the fireman is more efficiently sheltered from the weather than is usual on other engines. The severe climate of Nebraska and Wyoming in winter necessitates a very efficient protection for the men working the engines, and the arrangement shown, we are told, is found to answer well.

The engine referred to above is one of a large class built by the Rogers Locomotive Works, of Paterson, New Jersey, for the Union Pacific Railway, from the designs of Mr. Clement Hackney, Superintendent of Motive Power of that line. Further illustrations of American locomotives will be found on the large plates at page 680.

MODERN HIGH DUTY PUMPING ENGINES.

See Stationary Engines, pages 150–346.

The Holly-Gaskill High Duty Pumping Engine was designed by Mr. Harvey F. Gaskill in 1881, and first introduced at the Saratoga Springs, New York, water works, by the Holly Manufacturing Company, of Lockport, New York, in 1882, and has since been duplicated in various sizes in many prominent public works in the United States: notably at Philadelphia, Boston, Chicago, Washington and Buffalo.

The engine is horizontal, of the rotative beam non-receiver compound type, and involves several novel features of construction,

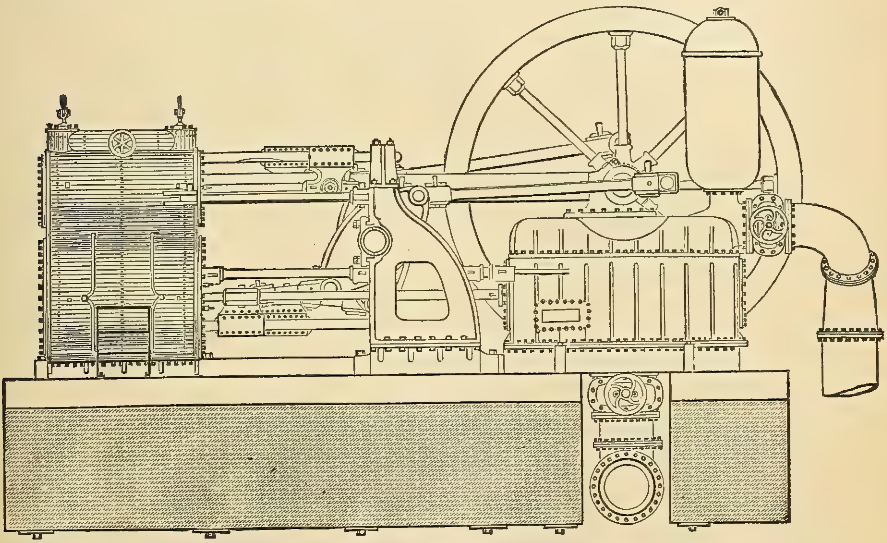


Fig. *a*.—Side Elevation.—Holly-Gaskill Pumping Engine, Saratoga Springs Water Works.

whereby a large capacity and a high economy are obtained by a simple machine in a small compass.

In its construction a heavy cast-iron bed plate is provided, upon which are mounted two double-acting reciprocating plunger pumps, and in direct line therewith two low-pressure steam cylinders (see accompanying cuts), with the piston rods of the latter connected directly to the piston rods of the former.

Between these pumps and steam cylinders there are placed two beam supports, which are firmly bolted to the bed plate and rigidly

stayed by wrought-iron struts to the pumps and steam cylinders. These beam supports carry the beam shafts and beams, the lower end of the latter being connected to the cross-head of the low-pressure cylinders by suitable links.

On top of the pumps are placed heavy bearings supporting the

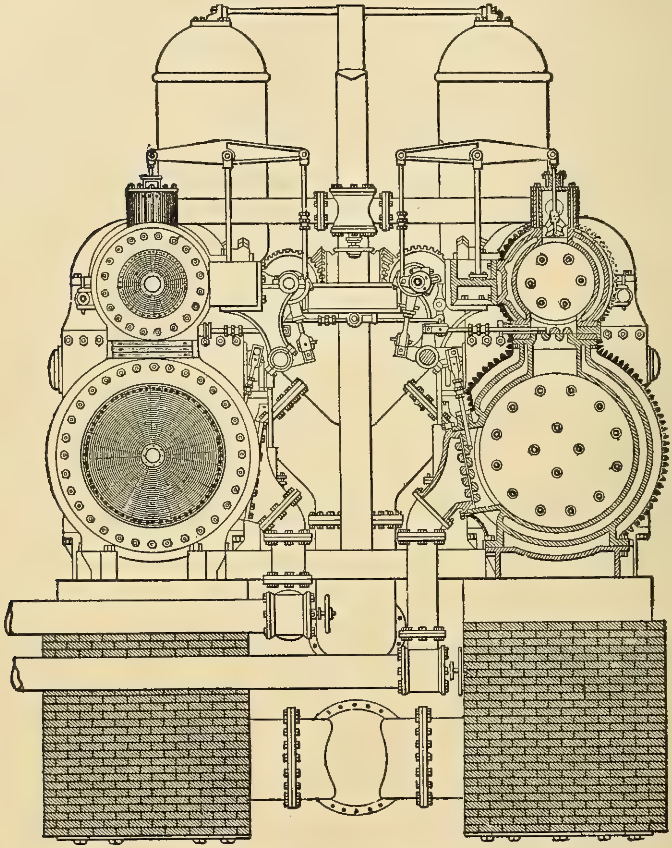


Fig. *b*.—External and Sectional End Views of Steam Cylinders.—Holly-Gaskill Pumping Engine, Saratoga Springs Water Works.

main shaft and fly-wheel, which are common to both pumps and the cranks, the latter being keyed to the shaft at quarters or right-angles to each other.

On the tops of the low-pressure steam cylinders are mounted two high-pressure steam cylinders with their centres in the same horizontal plane as the centre of the main crank shaft. Two cross-

heads for the high-pressure steam cylinders are connected by links to the upper ends of the beams, and the beams are in turn connected to the crank pins by connecting rods of the usual form, so that each pair of steam pistons drive one pump. The steam cylinders are all steam jacketed, sides and heads, the condensation from which is trapped back to the boilers.

On the inner end of each beam shaft an arm is keyed, from which the air pumps are driven.

All the valves of the steam cylinders are operated by eccentrics keyed to two counter-shafts, which are placed at right-angles with the main shaft, and are driven therefrom by two pairs of mitre gears.

The steam valves of the high-pressure cylinders are of the double beat poppet pattern, and are arranged so that they will always open at the beginning of the stroke, but may be adjusted to cut off the steam at any desired point of the stroke at the will of the engineer.

The exhaust valves of the high-pressure cylinders are of the ordinary slide valve type, placed intermediate to the high and low-pressure cylinders, and render double service as exhaust valves to the former and admission valves to the latter. They are set so that they will remain open until the stroke is nearly completed, allowing the steam to pass directly and freely from the upper to the lower cylinders. The exhaust valves of the low-pressure cylinders are of the same type, and operate in the same manner.

The pumps are of the double-acting plunger type, and work reciprocally through internal packed glands in the centres of the pump chambers. The pump valves are fixed in horizontal plates below and above the line of plunger travel, those at one end of the pump being divided from those of the other end by the plunger glands. Man-hole plates are provided for access to the plungers, glands and pump valves. These pump valves are of a peculiar form, as shown by the accompaning full-sized cut. Their diameter being small, the lift is slight, and yet sufficient to give an area of waterway which is uniform throughout. The same size is used in all pumps, the number being proportioned to the quantity of water required. They open and close quickly and silently, and the loss of water by slippage is slight, in some instances less than one per cent.

The operation of the machine is as follows:

Steam is admitted through the double beat poppet cut-off valves

into the high-pressure steam cylinders, and forces the piston forward under full boiler pressure until the point of cut-off is reached. These valves then close quickly, and the remaining portion of the stroke is accomplished by the elastic force of the steam. When these pistons have nearly reached the end of their stroke, the ex-

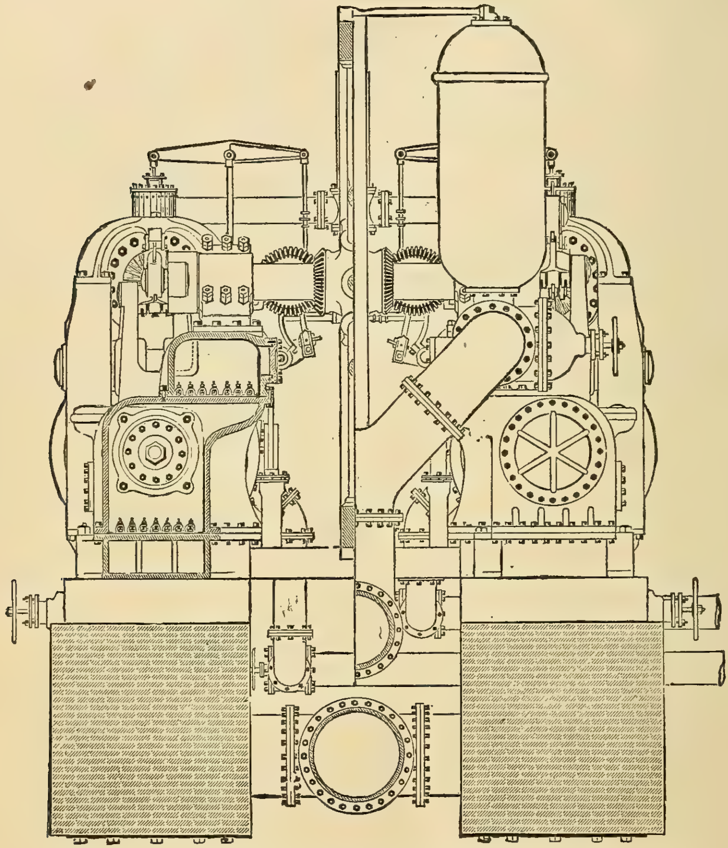


Fig. c.—Sectional and External End Views of Pumps.—Holly-Gaskill Pumping Engine, Saratoga Springs Water Works.

haust valves between the high and low-pressure cylinders open, and the steam in the high-pressure cylinders passes immediately into the low-pressure cylinders and against their pistons, which are then at the end of their stroke and opposite the high-pressure pistons. The low-pressure pistons are then in turn pushed forward by the incoming steam, which at the end of the latter's stroke is expanded

to four times the volume it had in the high-pressure cylinders at the time of its release therefrom. The release from the low-pressure cylinders is accomplished in the return stroke through the exhaust valves into the condenser. This operation is repeated in each pair of cylinders and at each end alternately. The close connection between each pair of high and low-pressure cylinders reduces the clearance spaces to a minimum, which with thorough jacketing insures the most economical use of steam.

This engine is built to operate as a non-compound engine, in which case the upper or high-pressure cylinders and connections are omitted, the poppet cut-off valves being placed on the lower cylinders and steam admitted to them direct from the boiler, and then exhausted into the condenser. This mode of construction reduces the cost, and may be preferred wherever fuel is so cheap that economy in the use of steam becomes a less important matter than the purchase price of the machine itself. When constructed in this way the duty of the engine is reduced about thirty per cent. as compared with the compound engines.

The more valuable features and peculiar merits of the Holly-Gaskill pumping engine are as follows:

First	High fuel economy.
Second	Moderate first cost.
Third	Low piston speed.
Fourth	Simplicity of design.
Fifth	Accessibility of parts.
Sixth	Perfect steam distribution.
Seventh	Perfect pump action.
Eighth	Uniform length of stroke.
Ninth . . .	The rough steam jacketing.

This engine at Saratoga Springs was subjected to the most critical and severe tests by Professor David M. Greene, Director Rensselaer Polytechnic Institute, Troy, N. Y., on the part of the builders; and John W. Hill, M. E., of Cincinnati, Ohio, in behalf of the Saratoga Water Board, in November, 1882; the result of which, as officially reported, was a duty of 112,899,993 pounds of water raised one foot, with one hundred pounds of coal consumed under the boilers, without frictional resistance or loss of effect, and without any deductions for ashes, clinkers, or unburned coal which had

fallen through the grates. The trial was a continuous run of twenty hours; the coal burned was Lackawanna of excellent quality; the average water pressure, 96.17 pounds; average steam

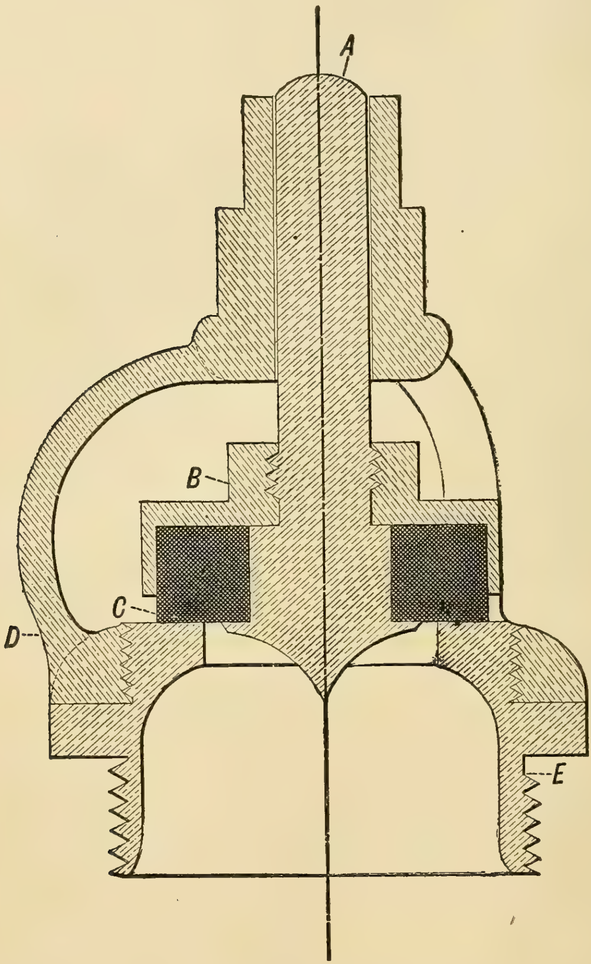


Fig. *d*.—Pump Valve, Full Size.—Holly-Gaskill Pumping Engine, Saratoga Springs Water Works.

pressure, 74.25 pounds; average vacuum, 27.28 inches; average temperature of feed water to boilers, 169.17 F.; speed of pistons, 107.25 per minute; area of pump plungers, 307.88 square inches; total revolutions during the trial, 21,449; length of stroke, thirty-six inches; and total coal burned, 6,750 pounds.

These remarkable results were questioned by some of the town officials; and, at their request, a subsequent trial was made under the sole direction and care of Professor Charles T. Porter, inventor of the Porter-Allen Steam Engine, in June, 1883, for a continuous run of sixty hours; resulting in an actual duty of 106,838,000 foot-pounds for the entire time, with an apparent duty for the first twelve hours of 127,170,000 foot-pounds per 100 pounds of coal actually consumed. It should be stated that the coal used during the last part of this trial was of inferior quality.

The official reports of the Saratoga Water Commissioners give this engine credit for an average duty in regular daily service for the years 1884 to 1890—six years—of 105,910,739 foot-pounds per 100 pounds of coal, no deductions whatever being made for ashes, steam for heating, or other purposes.

Duty trials of other Holly-Gaskill engines of this type show the following equally remarkable results:

Philadelphia, Pa.,	1888,	125,022,730	foot-pounds.
Buffalo, N. Y.,	1885,	125,907,297	"
Buffalo., N. Y.,	1889,	122,255,512	"
Dayton, Ohio,	1889,	124,782,157	"
Erie, Pa.,	1887,	122,309,829	"
Chicago, Ills.,	1886,	110,632,166	"
Chicago, Ills.,	1887,	102,583,585	"
Chicago, Ills.,	1889,	108,600,000	"
Washington, D. C.,	1888,	101,772,977	"
Columbus, Ohio,	1884,	115,400,000	"
Boston, Mass.,	1888,	109,421,000	"

Also at Jackson, Michigan; Leavenworth, Kansas; Kalamazoo, Michigan; Lima, Ohio; Port Huron, Michigan; Springfield, Ohio; each of which shows a duty exceeding 102,000,000 foot-pounds.

THE WORTHINGTON PUMPING ENGINE.

Worthington Compound Condensing Engines of large capacity and power, and of the form and type herein described, have been erected in nearly five hundred pumping stations, with an aggregate daily pumping capacity of over two billion gallons. Beside these, non-expanding and compound engines, ranging in capacity from the delivery of a few gallons a minute to several millions a day have been constructed to the number of over fifty thousand.

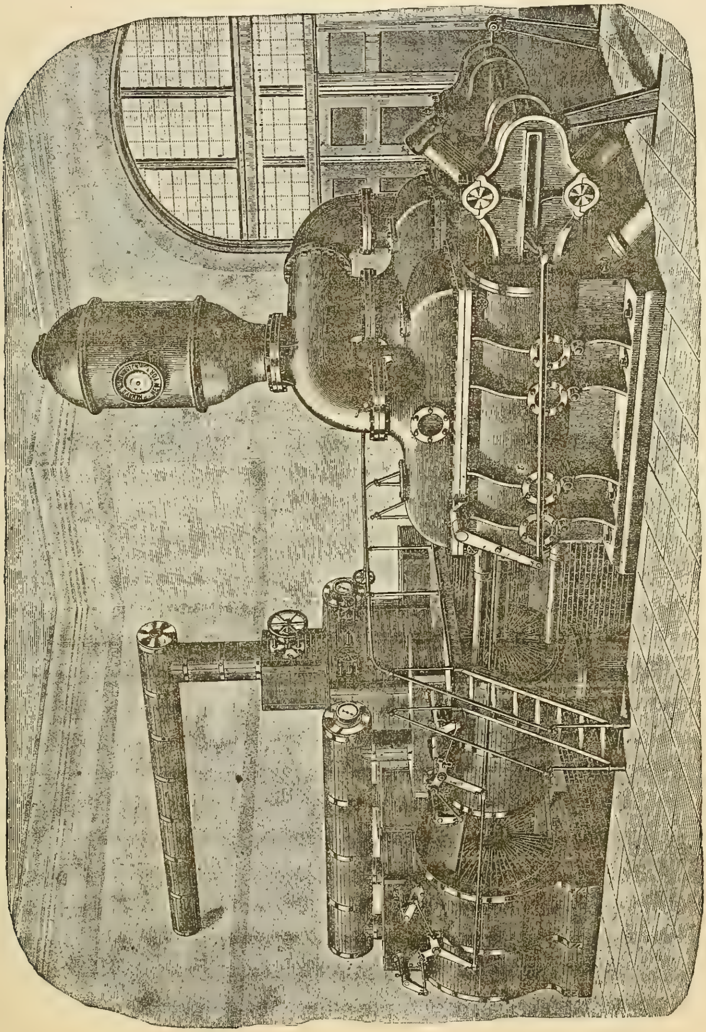
In referring to its surprising growth, the well-known engineer, Mr. E. D. Leavitt, remarks, in a paper read before the Montreal meeting of the British Association of Scientists in 1884:

"This (the direct-acting) class of pumping machinery deserves a prominent place, as the number in use vastly exceeds those of all other types combined. The first consideration will be given to the Worthington, which is the pioneer of its type, having been invented by the late Henry R. Worthington, and patented in 1844. Mr. Worthington's first pump was designed for feeding boilers. His first water-works engine was built for the city of Savannah, Ga., and erected in 1854. . . . In 1863 Mr. Worthington brought out at Charlestown, Mass., his crowning success, the Duplex Engine, which fairly deserves to be placed first among the hydraulic inventions of this century. This engine has since been more extensively duplicated for water-works purposes than any other. . . .

"Mr. Worthington and his successors have supplied 214 separate water works with 242 engines, having an aggregate daily capacity of 910,000,000 gallons.* This is equivalent to upwards of 40 per cent. of the estimated capacity of all the water-works pumping engines in America. The Duplex Engines have been made of capacities varying from 500,000 to 25,000,000 gallons per day. Their action is so smooth and perfect as to excite the admiration of all beholders. Briefly described, the Worthington Duplex, as constructed for water works, consists of two horizontal tandem compound engines, each of which is connected to a double-acting water plunger by a

* Since these figures were given in 1884, the number of Water-Works Engines built by Henry R. Worthington has been increased to over 500, having an aggregate daily capacity of more than 2,000,000,000 gallons.

continuation of the high-pressure piston rod. The high-pressure cylinder is usually secured in the front head of the low-pressure, the latter having two piston rods passing through long, sleeved



THE WORTHINGTON HIGH DUTY PUMPING ENGINE.

stuffing-boxes outside the high-pressure, and keyed to a cross-head, which has also the high-pressure piston and plunger rod secured to it. The steam and water ends of the machine are connected by

turned wrought-iron cradle bars, as they are termed, which make a light and strong connection. From the cross-head suitable links operate bell-cranks, which work two single-acting vertical air-pumps for each engine. These bell-cranks also give motion to the steam-distribution valves, which are slides working over double ports; and the valve for one side (as it is termed), or one engine, strictly speaking, is worked by the bell-crank of the other, which enables an almost constant flow of water to be maintained in the discharge pipe. The water valves are simple rubber disks working over brass gratings, and closed by weights or springs. Mr. Worthington is entitled to the credit of having introduced multiple valves for pumps. The later Duplex Engines are provided with cut-off valves, independent of the main slides."

The terms "High Duty" and "Low Duty," as applied to pumping engines, are used mainly to distinguish between two different grades of performance with reference to the consumption of fuel. In submitting propositions for furnishing pumping machinery for water-works, "Low Duty" is, generally speaking, held to comprise engines upon which a guarantee of duty is made of from fifty million to seventy million pounds of water raised one foot for each one hundred pounds of coal burned. "High Duty" comprises engines of a guaranteed duty of from ninety-five millions to one hundred and ten millions, and slightly above. All other things being equal, the great object in view in pumping water is to do the work with the least practicable consumption of fuel, which in turn simply means the least possible steam used by the engine. The *most* steam is used by a pumping engine when the steam follows the pistons from the beginning to the end of their stroke without any expansion whatever. The least steam would be used when the inlet valves close, and are caused to "cut-off" the steam at the earliest point in the stroke consistent with surrounding conditions. Steam following the piston "full stroke" means the largest consumption in proportion to work done. Theoretically, the highest practicable expansion of steam means the greatest economy. The load upon, or resistance to, a pumping engine is uniform, and therefore the propulsive energy of the machine must be practically uniform, either directly by virtue of the action of steam upon the pistons, or if the impulse of the steam is variable, its excesses and

deficiencies must be made good by the mechanism of the engine itself.

The Worthington Duplex Pumping Engine, although so widely used in water-works stations for the past thirty years, was, owing to peculiarities not necessary now to discuss, comparatively limited in its capabilities of expanding steam. This limited steam expansion relegates the Worthington engine of the past to the class of "low duty" machinery of to-day. In expanding steam to an extent that will secure a duty of one hundred millions of foot-pounds, the variable impulse of the steam during the piston's stroke makes imperative the demand for some means for reducing the wide variations of steam pressure to a uniform level. The problem presenting itself is this: At the beginning of the stroke the impulse of the steam upon the pistons is far in excess of that demanded for moving the load; at the terminus of the stroke the impulse of the steam is very much less than what is required; the mean pressure during the stroke is sufficient, but the inequalities must be instantly equalized when they occur, or else the engine will start with a violent plunge, and stop short of the end of its stroke at a point where the driving forces sink below what is demanded by the resistance. In the crank and fly-wheel engine this equalizing effect is brought about by a ponderous fly-wheel, which absorbs by its inertia the excess of energy at the beginning of the stroke, and gives it out at the end. In other words, the steam impulse upon the pistons in excess of what is actually required to move the load at the beginning of the stroke, is expended in inertia in trying to increase the speed of the fly-wheel; while near the end of the stroke, when the expansion of the steam in the cylinders carries the pressure below a point that will balance the resistance, the load is moved along by the momentum of the fly-wheel, the result being that the steam action is made uniform through the medium of the fly-wheel.

In the Worthington High Duty Engine the same effects of high steam expansion are obtained, but the uniform distribution of the steam pressure is secured by an entirely different method, much simpler and more effective, and embracing none of the objections of the fly-wheel, and presenting many positive advantages.

Expansion by means of compound cylinders alone had apparently been carried in this engine to its practical economic limit, with such

steam pressure as is usually employed. What remained to be gained from it further could be secured only at the expense of certain features of construction that were most desirable to retain.

Some means were therefore to be devised by which the gain in efficiency, due to cutting off and expanding the steam in each cylinder by itself, could be secured. To accomplish this through the usual medium of a fly-wheel, or other device wherein the momentum of a moving mass is utilized for the storing and imparting of energy, would be to rob the engine at once of those distinguishing characteristics and advantages that had given it its reputation. To make this change, in short, would be to abandon entirely the Duplex principle.

A better method suggested itself, and one that has proved eminently successful. By means of a most simple attachment, greatly increased economy in running has been secured, while, so far as its construction or the quality of its action is concerned, the engine is left unchanged.

This improvement marks a most important and radical advance in the position and history of the direct-acting engine. It lifts it at once from the plane of a low duty engine and places it alongside, and perhaps in advance of, such engines as have attained the highest duties yet recorded. Instead of the engine being confined, as heretofore, to an expansion of steam due to the relative areas of the cylinders, it can now be run at such ratio as is found to be the most economical. In other words, any point of cut-off in its cylinders may be used.

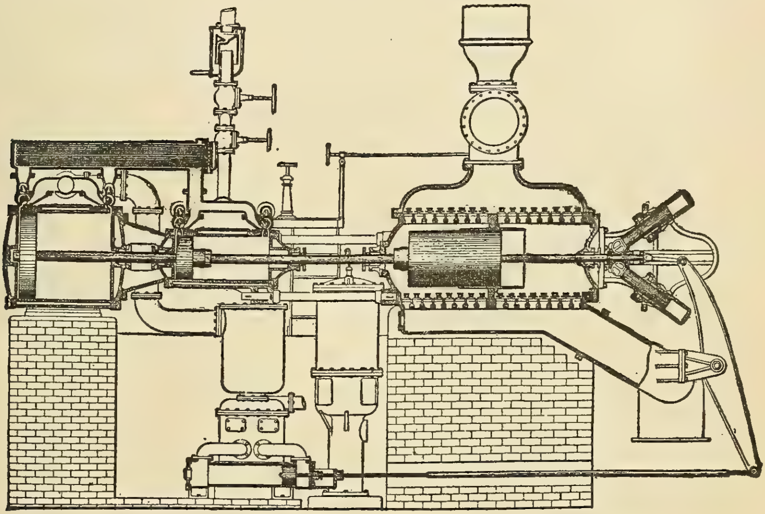
The attachment is shown in the illustrations on page cxliii.

It consists, briefly, of two small oscillating cylinders attached to an extension of the plunger rod of the engine, preferably beyond the water end. These cylinders and their connecting pipes are filled with water or other liquid, and connected, through the medium of an accumulator, with the water in the force-main of the pump. By this means a pressure on the pistons in these cylinders is maintained exactly equal to, or in proportion to, that in the force-main. These pistons act in such a way with respect to the motion of the engine as to resist its advance at the commencement of the stroke, and assist it at the end, the water in the force-main meanwhile exerting upon them a constant pressure at each point of the stroke.

The two cylinders act in concert, and being placed directly op-

posite each other, relieve the cross-head to which they are attached, of any sliding frictional resistance, and the engine of any lateral strain.

By alternately taking up and exerting power through the difference in the angle at which their force is applied with respect to the line of motion of the plunger rod, these two cylinders, in effect, perform the functions of a fly-wheel, but with the important mechanical difference that they utilize the pressure in the force-main instead of the energy of momentum. Whatever pressure is in the force-main



THE WORTHINGTON HIGH DUTY PUMPING ENGINE.
Sectional view.

is directly communicated to the compensating cylinders, and any variation in the force-main pressure is followed instantly by a corresponding variation in the cylinder pressure. Thus a uniform relation is maintained between the load on the pump plungers and the work performed by the compensators.

Their action is readily controlled, and their power is automatically proportioned to the work to be overcome, and is entirely unaffected by the speed of the engine. The same amount of expansion can be obtained in the same engine whether running at a piston speed of ten feet per minute, or at one hundred and fifty. This latter feature is of great importance, affecting as it does so favorably the economy

of the engine when applied on any service where the demand is irregular or intermittent.

Its economy is not appreciably affected by the widest differences in its speed, as the rate of expansion in the steam cylinders is constant under all changes in the rate of delivery of the pump. The engine adapts itself exactly to the load; as the pressure in the compensating cylinders varies proportionally with the pressure in the force-main, the result is a uniform propulsion of the water column and an absolute control of the speed of the engine, without dependence being had upon any automatic governor or other complicated device. Should the force-main or distributing-pipes burst from any cause, no accident can occur to the engine itself, as the loss of pressure in the main results in a corresponding loss of power in the compensating cylinders, until, when the pressure is entirely withdrawn from them, the engine is unable to complete its strokes.

The work of the compensating cylinders can, at the will of the attendant, be thrown on or off the engine instantaneously. Should they or the cut-off mechanism become in any way disarranged, or require overhauling or repairs, they can be quickly disconnected from the engine, which can then be run as economically and satisfactorily as though originally constructed without them.

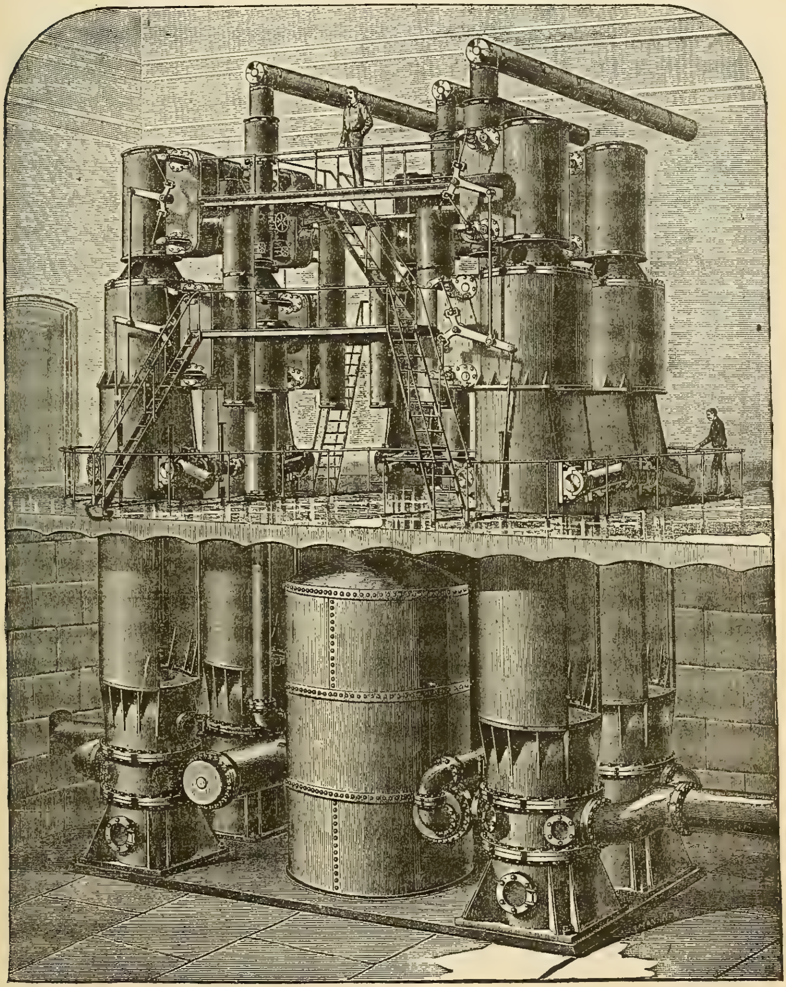
Where the most economic results are desired, the low-pressure as well the high-pressure cylinders are provided with cut-off valves. These consist of semi-rotating circular slide-valves placed in the admission ports of the cylinders, and operated by means of the direct connections illustrated in the engravings. As will be seen, their action is secured without the use of any eccentrics, gears or cams. When the point of cut-off has been once fixed, it need never be altered.

Worthington engines, with this attachment, have been fully tested under all the conditions to be met with in actual practice, and have achieved as high a duty as has heretofore been secured by an engine of any other type. A duty of one hundred million (100,000,000) foot-pounds, with the consumption of one hundred pounds of coal, can be considerably exceeded with an engine developing less than one hundred horse-power.

"Vertical Direct-acting Pattern."

The illustration represents a Worthington Vertical Direct-acting

Pumping Engine, with double-acting outside packed plungers. It involves precisely the same principles of construction as the regular horizontal engine, excepting the balancing device, which exactly



THE WORTHINGTON VERTICAL HIGH DUTY PUMPING ENGINE.

balances the weight of the moving parts. Two double-acting vertical plunger pumps are securely bolted to the foundations, which in turn support the superstructure to which is secured the low-

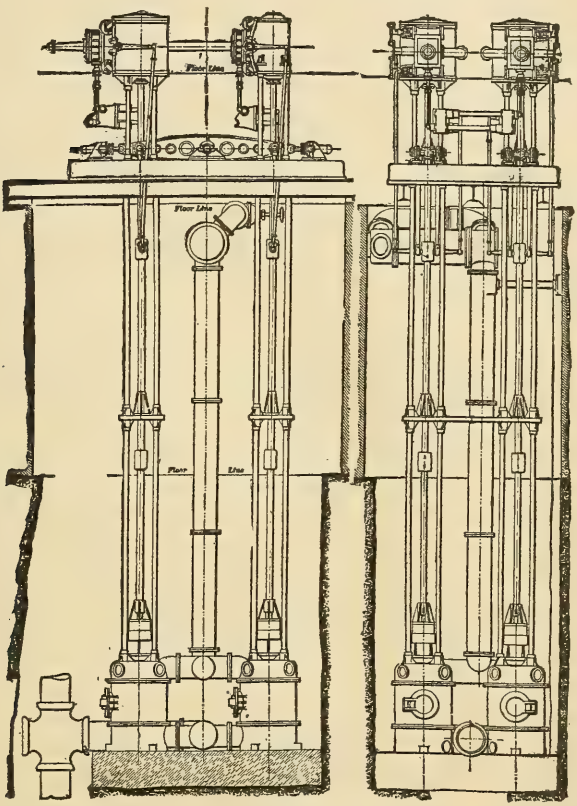
pressure cylinders. Above these cylinders extends suitable framing for attaching the high-pressure cylinders, and in this framing, between the high and low-pressure cylinders, are located the bearings for the compensating cylinders of the High Duty Attachment. This design embodies all the essential features of the ordinary Worthington engine, modified only to an extent sufficient to meet the conditions imposed by the vertical position of the machinery. The distance between the pumps proper and the steam-end of the machine can be varied to suit any demand necessary to comply with the situation as regards rise and fall of the water supply, at the same time keeping the steam part of the engine above high-water mark. The steam cylinders can be placed at a point high enough to prevent their being flooded by a rise of water, and at the same time, the pumps, or water-end of the engine, may be placed low enough to be within easy suction lift when the source of supply has fallen to its lowest stage. This form of the Worthington High Duty Engine is applicable to the variable service demanded in cities and towns situated on the western rivers. The steam expansion, pump action, work of the compensators, and all of the various features of the horizontal High Duty Engine will be found completely carried out in these Vertical Engines. Three of these engines, as shown in the illustration, each having a daily capacity of 10,000,000 gallons, have been built for the Artesian Water Company of Memphis, Tenn., and are now in successful operation. Two engines of practically the same type, each having a daily capacity of 12,500,000 gallons, have been built for the city of Cincinnati. A Worthington Direct Acting Vertical Pumping Engine has also been furnished for use at the new St. Clair Tunnel. This engine has a daily capacity of 5,000,000 gallons, and its water-end is placed at a distance of 125 feet below the steam cylinders.

This general type of engine is also made with inside plungers working through composition sleeves, and embodies all of the essential features of the above engine, being modified only in such unimportant respects as pertain to the change in the form of plungers.

"Vertical Beam Pattern."

An outline engraving of the Vertical Water-Works Beam Engine is shown on page cxlvii. This type of the Worthington engine also embodies all the essential features of the regular horizontal machine.

It is made with four single-acting outside packed water plungers, one plunger directly beneath each steam cylinder, the connections between the steam pistons and the plungers being made direct and rigid. Four single-acting water-cylinders are secured to the foundations below, and two strong, heavy bed-plates are supported by and secured to the walls of the pump-pit or foundations above, as shown.



VERTICAL WATER-WORKS BEAM ENGINE.

Rigid connections, or distance-bars, extend from the pump cylinders to the under side of the bed-plates, thus making the engine entirely self-contained as far as the working strains are concerned. The working beams are supported in centre bearings, bolted to the bed-plates, and are connected at their ends to cross-heads attached to the piston rods beneath the steam cylinders. The high duty com-

pensating cylinders are supported in pillow-blocks at the ends of the bed-plates, engaging with the ends of the working beams, one cylinder at each end of the beam so arranged as to give a direct effective distribution of their energy in equalizing the power of the engine, and concentrating it upon each plunger in succession. The engine is, naturally, perfectly and completely balanced by virtue of its design and arrangement, without regard to its height or distance between the steam and water ends of the machine. As already pointed out, this form of the Worthington engine can be readily adapted to places where the water from which the pumps draw their supply is liable to wide variations of level. At the lowest stages of the water the suction lift is from twelve to fifteen feet, while in time of flood the water level is many feet above the pumps, although the steam cylinders and working parts are out of reach of overflow. Both of the forms herein illustrated of the Worthington Vertical Pumping Engine can be adapted to be run either high or low duty.

The Application of the High Duty Engine to the Direct Pressure System.

In applying the High Duty Engine to the direct system of water supply, it has been provided with ready means for quickly increasing its power so as to meet promptly and effectively the demands of fire service. The arrangement employed is simple and complete, and involves only the quick and convenient adjustment of the cut-off valves to meet any fire pressure within the scope of the engine, thus suddenly changing the machine practically to the regular "low duty" type.

The peculiar automatic operation of the compensating cylinders of the high duty attachment is most clearly illustrated when the engine is working under the direct system of water supply. If the water pressure increases slightly, and so offers more resistance to the plungers, this very increase of load upon the engine produces a corresponding increase in the power of the compensators, exactly meeting the additional demand for power to produce a full stroke; while, if a fall of pressure occurs and the plungers should thereby become somewhat relieved and develop a tendency to excessive motion, the corresponding loss of power in the compensators precisely counteracts all inclination towards irregularity.

Several Worthington High Duty Pumping Engines have also been constructed for the United Pipe Lines that can deliver 25,000 barrels of oil in twenty-four hours against a pressure of 1,500 pounds per square inch. The engine made by this company for the Paris Exhibition of 1889 is the largest direct-acting pumping engine in the world. It has 41-inch high-pressure steam cylinders, with 82-inch low-pressure steam cylinders, driving 12-inch double-acting plungers, and is supplied with steam at a pressure of about 100 pounds per square inch. The High Duty Attachment on this engine weighs about 3,500 pounds, and when the engine is running under sixteen expansions and at a piston travel of sixty-five feet per minute, it is estimated that the compensating cylinders are developing an energy that could not be imparted by a fly-wheel of a less diameter than forty feet and weighing four hundred thousand pounds.

Description of Indicator Cards.

The Steam Engine Indicator has probably been the most useful and important means ever discovered for enabling the designing engineer to arrive at desirable and appropriate proportions, in constructing steam engines. By its use the action of the forces at work in a steam engine is clearly exhibited, not only of the steam itself, or in a pumping engine of the water as well, but also all the various effects of inertia, friction, movement of the reciprocating parts, etc., etc. By a combination of different diagrams many interesting and instructive results are obtained, which by careful study will point out the way of improvement, or reveal the otherwise hidden causes of observed effects, thereby enabling the designer to make such modifications here or there, as the case may require, in the attainment of any desired results.

As an illustration of the precise, automatic and uniform effect of the high duty feature of the Worthington engine, are shown some combinations of indicator cards on pages cl and cli.

In all pumping engines there are two completely antagonistic elements to be reconciled, viz.: an elastic expanding vapor at one end, and an inelastic non-compressible fluid at the other. In moving the fluid an effect must be obtained as near absolute uniformity as possible, while, to secure the greatest economy of steam expansion, it is necessary to produce the widest practicable variation of pres-

sure upon the steam pistons. It is obvious, then, that some means must be provided within the engine to equalize these widely differing demands, and the completeness with which the compensating cylinders of the Worthington High Duty Engine meet these requirements is plainly shown by considering the steam cards from the engine in conjunction with the action of the compensating cylinders.

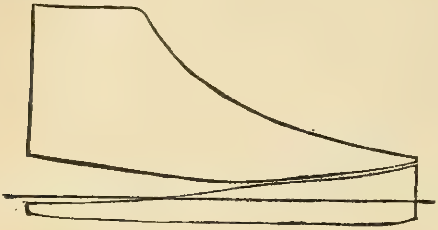


FIG. I.—STEAM CARDS.

Fig. I is an indicator card with diagrams from both high and low-pressure cylinders; Fig. 2 is a card from the water-end or pump of the same engine; these cards being taken from a Worthington five-million gallon engine in service, running regularly against an average water pressure of 107 lbs. It will be observed that the variation of pressure in the steam cylinders, as is always the case where high expansion is employed, is *nearly* 100 *lbs.*, whereas the card from the pump is *practically uniform.* Fig. 3 shows the high and low-pressure diagrams both reduced to a single diagram based upon the low-pressure piston area, which shows the actual variation in *steam* propulsion during the stroke. Fig. 4 represents the water card reduced to the same scale as Fig. 3, and indicates the absolute uniformity throughout the stroke, in striking contrast to the wide variation shown by the expanding steam in Fig. 3.

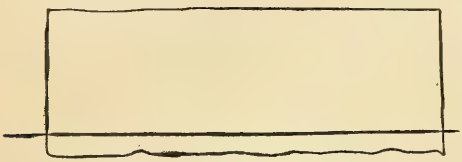


FIG. 2.—WATER CARD.

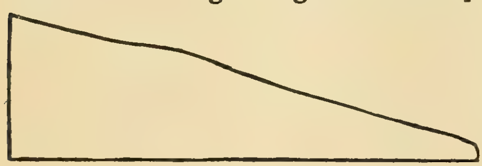


FIG. 3.

As explained previously, the action of the compensating cylinders of the high duty attachment is, in effect, to resist the steam pistons the first half of the stroke, and to help them drive the load during the last half of the stroke. Fig.

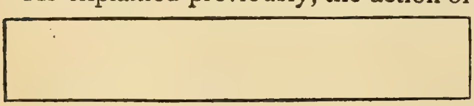


FIG. 4.

5 shows how efficiently they perform this important work. The diagram in Fig. 5 is formed by overlaying the steam card in Fig. 3 with a curved line representing the pressure exerted by the compensators. The shaded portion of the diagram gives the net effect of propulsion derived from the steam pressure upon the engine pistons in *conjunction* with the action of the compensators. The remarkable uniformity of the combined effort is indicated by the *nearly equal width* of the shaded portion of the diagram throughout the stroke; and to present a still closer comparison between the propulsive energy of the engine and the demands for uniformity made by the water card (Fig. 4), we produce Fig. 6 by overlaying the water card with the shaded part of the diagram in Fig. 5.

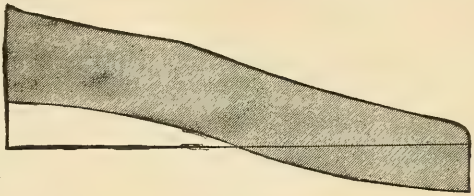


FIG. 5

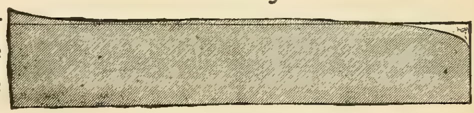


FIG. 6.

It will be observed that the propulsive energy indicated in Fig. 6 is slightly above the water card during nearly the whole stroke, just enough to cover the friction of the engine. At the end of the diagram (to the right) is shown how the momentum of the moving parts of the engine assists in finishing the stroke, until they are arrested in their movement by the cushioning effect produced in the steam cylinders. The indicated energy of the steam power as controlled and distributed by the high duty attachment, showing an almost exact coincidence with the straight line forming the top of the water card, explains why the action of the Worthington High Duty Engine is absolutely smooth and noiseless.

HIGHEST SPEED ATTAINED BY LOCOMOTIVES.

ENGLAND—THE HIGHEST RAILROAD SPEED TILL AUGUST 6, 1888.

An Edinburgh despatch to the New York *Times* says: *Flying Scotchman* has been beaten by the *West Coast Flyer.* When the London and Northwestern, or West Coast Express, ran into Edinburgh Station at 5.52 this evening, it broke all previous records of high railroad speed, not only for England, but in the railway world in general. This was the first day of the great 400-mile race between two of the biggest English Companies, and the faster train of the two traversed the greater part of that distance at a speed of a mile a minute.

Competition between the Great Northern and West Coast Companies began to grow lively a year ago, when the former, by adding third-class compartments to its Edinburgh limited express, took away the third-class passengers which the Northwestern had hitherto carried on trains going at a somewhat slower speed. Since that time the contest for Edinburgh travel has been active.

For the summer traffic, which is always very large, the Great Northern in June reduced its schedule time to 8½ hours. The West Coast Line met this figure July 1. Competition in England always cuts time and never cuts rates. Two weeks ago the Great Northern made a further cut to 8 hours and its rival followed suit. Great Northern trains began running in on the new schedule last Wednesday, but the West Coast did not begin until to-day. As the *Flying Scotchman* on the old 9-hour schedule was the fastest train in the world, the interest taken in to-day's race between the two trains, when both were sent through in 8 hours, was naturally great in railway circles and everywhere else.

In company with Assistant Superintendent Turnbull, of the West Coast Line, and William Acworth, railway expert of the London *Times*, I entered a first-class compartment at Euston this morning just before 10 o'clock. The West Coast was the better line to go by. It only had to get through in the same time to win, as its longer route compels it to make 1 mile per hour more than the

Scotchman. The 2 trains pulled out at the same moment, the *Scotchman* from Kings Cross and the West Coast from Euston. Everybody in our compartment flourished a watch. We could not time the rival train, but we were sufficiently interested in keeping view of our own iron horse, as that capable animal probably travelled faster than any locomotive ever did before for a continuous run. The engine had a single pair of driving-wheels, 7 feet 6 inches in diameter, and weighed 27 tons. It burned 24 pounds of coal per mile during the run. The tender, loaded, weighed 25 tons. Behind it were 4 coaches filled with passengers, making a weight of 20 tons each, or 80 tons in all. We started slowly. The run to Tring was up-grade, the steepest portion being a rise of 1 foot in 70. This distance, 31½ miles, was covered in 40 minutes. Once over the hill, the engineer woke up and began to show his mettle. The speed was increased steadily until our hair began to stand on end. Telegraph poles began to seem like fence posts and the roadside a medley of objects hard to distinguish. We knew we were going over 60 miles an hour, but were not prepared for the announcement that the speed was 72 miles. Mile-post after mile-post was registered at 50 seconds by our watches, and the 15 miles from Tring to Bletchley took exactly 12 minutes and 30 seconds. With a speed varying between 72 miles and that, we flew over the flat land, the spirits of the party naturally heightened by the novel experience after the first tendency to hang on to something wore off.

Fears now began to be entertained that we were going to stop at Rugby, as is usual with this train. The general desire was to keep straight on to Crewe, 158 miles, without halt, according to schedule, and the fears of a stop at Rugby arose only from the fact that we were several minutes ahead of time. Rugby was passed without halt, however, the 82¾ miles from Euston having been done in 92 minutes. The same speed was kept up and Tamworth, 100 miles, was reached in two hours. The run of 95 miles from Tring to Tamworth was made in 100 minutes, which was considered pretty good. From Tamworth to Crewe took 58 minutes for 48 miles, and we ran into the latter station at 12.58, two minutes ahead of the schedule time. This run of 158 miles, without a halt, in 2 hours and 58 minutes, is the longest known to any schedule, being 12 miles longer than the Fort Wayne and Chicago run. Water was, of course, taken in from the track.

At Crewe we spent five minutes, exchanging our single-wheel driver for a 32-ton engine, with two pairs of driving-wheels. The moment we pulled out of the station it became evident that the engineer proposed to show what he could do. The landscape began to fly by us at an unprecedented rate, and watches began to register from 48¾ to 48 seconds for the following miles. This meant from 73¾ to 75 miles per hour. This speed was kept up for 8 or 10 miles, when the engineer, contented with his spurt, eased down to 60 miles an hour. From Hartford to Warrington we ran 12¼ miles in 11½ minutes. Warrington to Wigan, 12 miles, we did in 11 minutes. The engineer was allowed 58 minutes to make the run of 51 miles from Crewe to Preston, but he cut under the schedule and ran into Preston in exactly 51 minutes, an average of a mile a minute from platform to platform.

We spent 20 minutes at Preston for luncheon, leaving there at 2.18. Once out of town we clapped spurs to our animals and rose to 73 miles per hour. The run from Preston to Oxenholme, 40 miles, was made in 42 minutes, the last ten miles being up grade. A heavy grade of 75 feet was met at Teebay Junction, but we did the 5½ miles to Sharp Summit in 8½ minutes, this being at the altogether miserable run of 37½ miles per hour. Once over Sharp, however, we began to do 72 miles an hour again, and flew along down grade at this rate for 10 miles, when we slowed down and lounged along at the comfortable pace of 60 miles. A little rise caused further diminution, but the 31 miles, from Sharp to Carlisle, was done in 31 minutes. At Carlisle 10 minutes were spent and the engine changed for another with one pair of large drivers. As before, this was an engine specially constructed and which was exhibited in the Edinburgh Exhibition of 1886. With this we went to Beattock, 39¾ miles, in 39 minutes, now having rain against us and a wet track. From Battock the 10-mile climb to Summit, on a grade one in eighty, was done at the rate of 44½ miles per hour. Over the Summit the speed rose to 67½ miles, and the next 13½ miles took only 12 minutes. The 24 miles from the Summit to Carstairs was done in 22 minutes, and at a slightly less rate than a mile a minute we finished the 27½ miles to Edinburgh. We ran into the station at 5.52 o'clock, 8 minutes under the schedule. The 101 miles from Carlisle had been covered in 104 minutes, over a pass 1,015 feet high, and this run is simply unprecedented in railway annals.

The entire distance covered was 400 miles, and the actual time, including stops, was 7 hours and 25 minutes, an average of $53\frac{5}{8}\frac{3}{9}$ miles per hour. This has never been approached before for so long a run. The fastest continuous record in England hitherto was that of the special train which took the Prince of Wales from Liverpool to London, 200 miles, in 3 hours and 59 minutes, an average slightly over 57 miles.

After we arrived the *Flying Scotchman* thundered into the Waverly station. We had beaten it, however, not only 7 minutes in time, but 8 miles in distance, and this 8 miles superiority on the West Coast will continue as long as present schedule holds, which will be for several months at least. It is now said that Great Northern will cut to 7½ hours. I do not think it likely, however, as there is a large conservative party among the directors opposed to any faster speed. Consequently the West Coast train will bear off the palm henceforth.

Despite the fearful speed, the journey was not at all unpleasant. The jostling and lateral motion seemed no greater than when going at an ordinary speed. The sight from the windows was very unusual, however. Trains coming at full speed from the opposite direction went by with a crash like a volley of musketry and were indistinguishable brown-colored masses seen only for a moment.

A short tunnel was like a gas jet, suddenly extinguished and suddenly relighted, the eye not having time to accustom itself to the darkness. Long tunnels were passed through with a booming roar and a continuous shower of sparks. Against the blackness it was quite like an effect in fireworks. There was no more danger in the trip than in one at the ordinary speed, and the only noticeable difference was a slight shakiness of the legs upon getting out. All the passengers bore the trip well except one lady, and the eight-hour express, which will continue through the summer months, will undoubtedly be a popular train.

[*From the Philadelphia Evening Telegraph, August* 8, 1888.]

AMERICA'S SPEED RECORD.

The liveliest interest was manifested yesterday by railroad men in the cable account of the race between the *Flying Scotchman* and the *West Coast Flyer* from London to Edinburgh, in which 400 miles were covered by the winner in 7 hours and 25 minutes. This was

an average of something over 53½ miles an hour. There was a general jogging of memories and overhauling of the records of fast railroad trains on American lines. And much comfort was found by many in going over those records. For they show that, although the British and French roads admitted make much better time habitually than is made on any of the American lines, some astonishing and sustained rates of speed have been attained here, when special efforts were expended with that end in view.

The best run on record in this country which can be fairly compared with the English run was made over the West Shore Road from Buffalo to New York on July 9, 1885, when 426 miles were covered in 7 hours and 27 minutes. Quite a large number of railroad men, including officials of the Baltimore and Ohio, Wabash, Grand Trunk, and West Shore Roads happened at Buffalo together en route for New York. It was decided to see how quickly they could move over the new road. At the start the railroad men had their watches out, and soon the mile-posts were flying past every 43 seconds. That speed was held so steadily that the greater part of the run was made at the rate of 45 seconds to the mile, or from 70 to 83 miles an hour. From East Buffalo to Genesee Junction, 61 miles, took 56 minutes; from East Buffalo to Newark, 93.4 miles, 97 minutes; from Alabama to Genesee Junction, 36.3 miles, 30 minutes. The 97 minutes to Newark included stops of 9 minutes, making the actual running time for the 93.4 miles 88 minutes. From Newark to Frankfort, where the conditions for running were not so good as before, the run of 108.3 miles was made in 134 minutes, including 17 minutes for stops. From East Buffalo to Frankfort, 202 miles, the time was 240 minutes, of which 35 minutes were consumed in stops.

On the New York Central Road a newspaper train with two cars weighing sixty tons hauled into Syracuse Sunday morning, August 8, 1886, at 10 o'clock, an hour late. The train was booked to go from New York to Buffalo in nine and one-half hours. Orders came to try and make up for the time on the further run of 148.7 miles to Buffalo. John W. Cool, one of the best engineers on the road, mounted his cab bound to obey the order. He started out at 54½ miles an hour. At the end of three miles his speed increased to 66 miles an hour, and then to 74½. He stopped at Rochester for water and slowed up after passing Crittenden. His average

speed from Syracuse to Rochester was 67¼ miles per hour; from Rochester to Buffalo, 63.72 miles per hour, and from Syracuse to Buffalo, 65.6 miles an hour. The run of 148.7 miles was made in 136 minutes.

The most remarkable long-distance run on record was when the Jarrett-Palmer combination went from New York to San Francisco in half time, or three and one-half days. Their train left the Pennsylvania station in Jersey City at 12.53 on the morning of June 1, 1876. They were not to make a stop until they reached Pittsburg. An engine and baggage-car, on the approach of the special to Harrisburg, got up a speed of about 50 miles and passed mails to the special by running along an adjoining track for several miles while the mail-bags were thrown from train to train. The run to Pittsburg, 438½ miles, took 10 hours and 5 minutes, an average of 43½ miles an hour, notwithstanding the Alleghenies. From Pittsburg to Chicago, 458.3 miles, took 11 hours and 6 minutes, an average of 42.1 miles, including twenty-five stops and four changes of engines. From Chicago to Council Bluffs, 491 miles, took 11½ hours, an average of 42.6 miles, although there was a record for part of this journey of 62.2 miles. Over the Union Pacific the run of 1032.8 miles from Omaha to Ogden was made in 24 hours and 14 minutes, at an average of 41 miles and a maximum of 72 miles an hour. The brakes became worn at Ogden and hand-brakes had to be used, retarding the onward journey somewhat, as the men feared that they might lose control of the train. San Francisco was safely reached at 12.57 on June 4th, quite in time for the dinner that had been ordered for the company for that day. The last stage of the journey was run at an average of 37 miles. During the entire run 20 engines were used, there were 72 stops, and the running time for 3313½ miles was 84 hours and 17 minutes, an average of 40 miles an hour.

On the Pennsylvania Road forty-five miles an hour is not uncommon, and there are level stretches where a speed of a mile a minute is attained. Samuel Carpenter, the General Agent of the road, said yesterday that if there was any need of making time to compare with the new English schedule, it could be done. On the New York Central Road the run of eighty miles from Rochester to Syracuse has been made in eighty minutes when it was necessary to make up lost time. Assistant Superintendent Voorhees, of the New

York Central, said that he stood ready any day to send a party from New York to Buffalo, 440 miles over that road, in the same time made by the English racer for 400 miles, if the party would pay two dollars per mile to get there in seven hours and twenty-five minutes.

Professor Arthur T. Hadley, of Yale, when interviewed upon the subject, said that he had been at work during a portion of the day in order to go over some of the best American railroad records. The result of his examination, he says, shows that the claim made by the Englishmen that the run made August 6th between Edinburgh and London broke all previous records for high railroad speed in England and the railroad world cannot be supported by fact.

THE LIMIT OF SPEED.

The speed of locomotives has not grown with their weight and size. There is a natural law which stands in the way of this. If we double the weight on the driving wheels the adhesion and consequent capacity for drawing loads is also doubled. Reasoning in an analogous way, it may be also said that if we double the circumference of the wheels, the distance that they will travel in one revolution, and consequently the speed of the engine, will be in like proportion. But, if this be done, it will require twice as much power to turn the large wheels as was used for the small ones; and we then encounter the natural law that the resistance increases as the square of the speed, and probably at even a greater ratio at very high velocities. At 60 miles an hour the resistance of a train is four times as great as it is at 30 miles. That is, the pull on the draw-bar of the engine must be four times as great in the one case as the other. But at 60 miles an hour this pull must be exerted for a given distance in half the time that it is at 30 miles, so that the power exerted and the amount of steam generated in a given period of time must be eight times as great in the one case as the other. This means that the capacity of the boiler, cylinders, and the other parts, must be greater, with a corresponding addition to the weight of the machine. Obviously, if the weight per wheel is limited, we soon reach a point at which the size of the driving wheels and other parts cannot be enlarged, which means that there is a certain proportion of wheels, cylinder and boiler which gives a maximum speed.—*M. N. Forney*.

SPEED ON THE RAIL.

WILL TRAINS EVER BE RUN AT THE RATE OF 120 MILES AN HOUR OR MORE? OPINION OF EXPERT WATKINS OF THE SMITHSONIAN INSTITUTION, WASHINGTON, C. D.

September 10, 1890.

"My opinion is that the speed limit of the locomotive engine has been reached with the present gauge of track and diameter of driving-wheel," said Expert Watkins, at the National Museum, to a Washington *Star* reporter. "I have been given to understand on very credible authority that an engine on one road has already made a record of 100 miles an hour—of course, over a very short distance of perfectly straight and level track. If that is to be beaten, it will only be done by increasing the size of the boiler, to begin with. To get a greater capacity of boiler it will be necessary to widen the locomotive, and therefore the track. If the speed of anything like 120 miles an hour is to be attained in the future, the track must be widened, not by inches, but by feet, and the size of the driving-wheel proportionately. Naturally the question of safety is the first one brought up in connection with a discussion on this subject, and it is asked, Can trains be run with as much security to life and limb at 120 miles an hour as at 50? My answer to that is: No. Take a given stretch of track, in perfect condition, with nothing in the way, and a train is more likely to run off the rail when going at 150 miles an hour than when travelling at 60. But such ideal conditions are not usually found in railroading. You must consider that there are such things as frogs and switches, which get out of order or misplaced, as well as a multitude of other things, more difficult to look out for the more rapidly trains are going. Most important to think of, too, is the fact that if an accident does occur the train that meets with it is going to suffer in proportion to the speed at which it is going at the moment of interruption. Two trains, each going at the rate of 120 miles an hour and coming into collision, would quickly be reduced to kindling wood, if not toothpicks.

"Another thing worth inquiring about is the number of men that are going to be required to run one of these engines of the future that are to travel 120 miles an hour. Jump on board of one of the fast-flying locomotives at Jersey City that carries you to Philadelphia at the rate of nearly a mile a minute. Do nothing but watch the signals as you pass with lightning speed through city after city at grade and across railway after railway intercepting. You will

find that it takes about all your time to catch them. How much leisure has the engineer, then, to look after his steam gauge and water gauge, to see to his air brake, to make sure that every part of his mighty machine is in order, to keep in touch with the train-despatcher's office and to identify any extra trains as they pass him, so that no mistake shall be made? So tremendous is the strain upon this man's nerves that as a measure of economy the company only permits him to work four days each week, and he spends the remaining three in resting and bracing up for further contests with space and time.

" Trains in England, on an average, run faster than in this country. Their cars or carriages are not nearly so heavy as ours; they have not nearly so many heavy grades and sharp curves, and the law gives the railway exclusive rights over their tracks, the infringement of which is punished by fine and imprisonment. In England one person out of every 2,250,000 people carried is killed. To ride on the railways in France is a great deal more dangerous, inasmuch as one out of every 2,000,000 passengers is killed. Belgium is much safer than England in this respect; only one out of every 9,000,000 is killed on its roads. Safest of all by far are the railways of Prussia, which only kill one out of every 21,500,000 people carried. There are many advocates in favor of making our railroad cars much lighter, the argument being that it is absurd to drag a whole row of houses over the rails in order to transport a lot of comparatively light packages in the shape of people. But it is very certain that heavy cars have the advantage of safety in proportion to their weight. You will notice that the passengers in the heavily-built parlor cars always get off with very much less damage in an accident than do the occupants of the ordinary cars, which are usually telescoped by the Pullman or Wagner coaches. Extra heavy weight to draw means extra expense for the railway companies, but safety for the passengers they carry means saving of money in damages in these days when juries are given to mulcting the companies severely in such cases. Of course, you read in the newspapers about the running of Boynton's bicycle engine at Brighton Beach the other day at the rate of a mile in thirty-two seconds, or 112 miles an hour. That may give a notion of the future of railroading as regards speed, but I am not myself of the opinion that the bicycle idea will work any revolution in the business of transportation by rail."

THE SONG OF STEAM.

[G. W. CUTTER. Born in Cincinnati, in 1818. A captain in the United States army during the invasion of Mexico.]

Harness me down with your iron bands,
  Be sure of your curb and rein;
For I scorn the power of your puny hands,
  As the tempest scorns a chain!
How I laughed as I lay concealed from sight
  For many a countless hour,
At the childish boast of human might,
  And the pride of human power!

When I saw an army upon the land,
  A navy upon the seas,
Creeping along, a snail-like band,
  Or waiting the wayward breeze;
When I marked the peasant fairly reel
  With the toil which he faintly bore,
As he feebly turned the tardy wheel,
  Or tugged at the weary oar—

When I measured the panting courser's speed,
  The flight of the courier-dove,
As they bore the law a king decreed,
  Or the lines of impatient love,
I could not but think how the world would feel
  As these were outstripped afar,
When I should be bound to the rushing keel,
  Or chained to the flying car!

Ha! ha! ha! they found me at last;
  They invited me forth at length;
And I rushed to my throne with a thunder-blast,
  And laughed in my iron strength!

Oh! then ye saw a wondrous change
  On the earth and ocean wide;
Where now my fiery armies range,
  Nor wait for wind or tide.

Hurrah! hurrah! the waters o'er
  The mountain's steep decline;
Time—space—have yielded to my power;
  The world—the world is mine!
The rivers the sun hath earliest blest,
  Or those where his beams decline,
The giant streams of the queenly West,
  And the Orient floods divine.

The ocean pales where'er I sweep,
  To hear my strength rejoice!
And the monsters of the briny deep
  Cower, trembling at my voice.
I carry the wealth to the lord of earth,
  The thoughts of his god-like mind;
The wind lags after my flying forth,
  The lightning is left behind.

In the darksome depths of the fathomless mine,
  My tireless arm doth play;
Where the rocks never saw the sun's decline,
  Or the dawn of the glorious day.
I bring earth's glittering jewels up
  From the hidden cave below,
And I make the fountain's granite cup
  With a crystal gush o'erflow.

I blow the bellows, I forge the steel,
  In all the shops of trade;
I hammer the ore and turn the wheel,
  Where my arms of strength are made.
I manage the furnace, the mill, the mint;
  I carry, I spin, I weave;
And all my doings I put into print
  On every Saturday eve.

MODERN STEAM PRACTICE
AND ENGINEERING.

COAL AND COAL-MINING.

COAL is the primary source of our commerce and manufactures, by enabling steam-power and machinery to be produced at the most economical rate. The economical importance of the coal deposits in England and Scotland is much enhanced by the rich beds of iron ore found in their associated shales, as well as in the contiguity of the carboniferous limestone which is required to assist in reducing the ore to a metallic state, not to speak of the lesser advantage of the proximity of the fire-clay, which furnishes the only material for building blast-furnaces capable of resisting the heat of the smelting process. The varieties of coal usually met with are anthracite, caking-coal, cherry-coal, splint-coal, and cannel-coal.

For manufacturing purposes coals are generally considered to consist of two parts—a volatile or bituminous portion, and a substance comparatively fixed, and usually known by the name of *coke*. This latter form of coal is extensively used in locomotive engines on railways, in consequence of its yielding no smoke, the volatile matter, or that which forms the smoke of coal, being removed by ignition. As the bituminous or volatile part of coal yields the gas used for lighting, it has been found that the heating power of the coal resides in the coke, and no heat is lost by first extracting the gas from coal by the usual methods of burning, or rather distilling coal.

Coal is deposited in beds more or less horizontal, although sometimes by movements of the earth's crust their position has become much inclined. The great coal-field of Britain, which is composed of numerous subordinate coal-fields, crosses the island in a diagonal direction, the south boundary line extending from near the mouth of the river Humber, upon the east coast of England, to the south

part of the Bristol Channel on the west coast; and the north boundary line extending from the south side of the river Tay in Scotland, westward by the south side of the Ochil Hills, to near Dumbarton upon the river Clyde; within these boundary lines North and South Wales are included. This area is about 260 miles in length, and on an average about 150 miles in breadth. Coal also occurs in other formations of later geological age; but none of these later deposits equal in economical importance the rich stores of the carboniferous system in our island. Beds of coal are found in most European countries, as also in China, India, Australia, Japan, and Borneo; but the coal-fields of the United States of America are by far the most extensive and richest in the world.

Boring in search of coal is an important branch of mining. In ordinary practice the boring plant consists of shearlegs, windlass, brake, brace-head, bore-rods, cutting tools, &c. Steam-engines specially adapted for boring have also been devised. A very simple method with hollow rods combined with a force-pump was introduced by M. Fauvelle in 1846.

The "troubles" met with in working coal are various:—for example, a "want" or "nip" is, as its name suggests, a part of the field where no coal exists, or only in a very thin streak; if this streak is followed, however, the coal seam will again be found. "Dykes" are generally of whin, projecting from below. It rarely happens that the coal is either elevated or depressed by this "trouble," but it is much burned and rendered useless for some yards on either side. A "step" or "fault" is a dislocation, sometimes of considerable magnitude, by which the strata are elevated or depressed many fathoms. A "hitch" is of the same nature as a "step," but on a smaller scale. A whin bed is perhaps the worst kind of "trouble" to be met with, as, when found near to and parallel with a coal-seam, it renders the entire bed useless. When a miner meets with a "step" or a "hitch" he at once knows whether it is an "up throw" or a "down throw." If a "hitch" lies off at the top, by following the rise upwards he will find the coal; if off at the bottom, he must follow the dip downwards. Although it is both annoying and expensive to meet with these "troubles," they often serve useful purposes: "steps," for instance, sometimes elevate the coal from a depth that would be difficult to reach by ordinary means to a depth of comparatively easy working. Again, when a coal-seam is nearly cropping out, a "step" is met with

that throws it down, in this way extending the field. Again, whin dykes serve the purpose of dams, and prevent water passing from one "waste" or worked-out space to another.

It is also of importance to fix on the best position and form for the pits. Where much water may be expected, the best form for the pit-shaft is circular, so that the water met with in sinking may be kept back by tubbing; that is, lining the shaft with suitable material, such as stone, timber, or cast-iron, the latter being preferred. When the pressure of water is great, sometimes the tubbing is formed of half rings, so as to fit the shaft; but where pumps and brattices interfere, segments of cast-iron are used, about 4 feet in length and 2 feet in height, and from ⅜ of an inch to 1 inch in thickness. The segments are made to form a smooth surface in the shaft, and they are fitted to each other by means of flanges, 3 to 4 inches at each end, and the spaces between the segments are filled up with thin deal. Stone tubbing is merely common walling, with the foundation made tight by means of grooves cut in the stone, the joints and backing being filled up with cement, which, if carefully executed, will answer for light purposes; but the success of this method of tubbing is of too precarious a nature to meet with general application for important works, and wood or iron is preferred. It sometimes happens in sinking pits that all the wells and springs in the neighbourhood are drained off, but this evil may be prevented by tubbing the shaft.

Some pits are sunk at great expense, owing to the nature of the strata which have to be passed through, and other difficulties, as, for example, a heavy flow of water. Such instances occur in the north of England, as at Pemberton's Pit, Monkwearmouth, near Sunderland, and a pit at Seaham near Durham, which is 300 fathoms deep and cost the enormous sum of £100,000. Before the steam-engine was introduced, the coal-pits capable of drainage with hydraulic machinery or water-engines were comparatively few in number; and when drained by wind-mills, as was sometimes the case, the pits were drowned in calm weather. The driving of day levels was thus a primary object with the early miner; and this system of draining is the cheapest where circumstances allow of its adoption. The day levels were often of sufficient dimensions to admit of roads, and even in some cases of canals, being formed in them, so that machinery was not required. In modern times, however, the water is pumped from great depths by steam power, the

single-acting Cornish pumping engine, having a beam with the steam cylinder at one end and plunger or force pumps at the other, being extensively used. Sometimes lift or bucket pumps are introduced, while in other cases both plunger and lift are combined in a single barrel. Some of these engines work direct, the pump rods being attached at once to the piston-rod over the pit.

The deleterious air met with in mines is of two kinds, the one being heavier and the other lighter than atmospheric air;—the natural consequence of which is that the heavier gas rests in the lower parts of the mine, while the lighter ascends to the higher parts. The heavier is carbonic acid gas, known to the miners by the names of "choke-damp," "black-damp," and "stythe;" the lighter gas is carburetted hydrogen, commonly called "fire-damp," or inflammable gas. Where the former gas has been allowed to accumulate there is great difficulty in getting it expelled. In coal mines it is seldom present except as "after-damp," and is the result of a preceding explosion. No light will burn in this gas. We have seen a fire-lamp, with about 3 cwt. of coal in full blaze, burning in a pit where choke-damp filled the bottom, as completely extinguished as if it had been plunged in water. At times, though seldom, the coal has been known to catch fire in mines, and burn for years; in such cases carbonic acid gas has been successfully applied in extinguishing these fires.

Carburetted hydrogen or "fire-damp," the lighter gas, is not explosive until mixed with atmospheric air. According to experiment, the mixture most explosive is 1 of gas to 6 of atmospheric air; when it is 1 to 14 a candle burns in it, but with a flame much elongated. Many of the fearful explosions and attendant loss of life occasioned by this gas arise from carelessness. Some obstruction in the air course is allowed to take place, a door has been left open all night, or a miner enters his room with a safety-lamp in his hand, but has neglected to remove the open lamp from his cap; even some of the miners are so fool-hardy as to light their tobacco-pipes by drawing the flame through the wire gauze, thus igniting the gas. We need not impress upon all workmen the great danger arising from such carelessness.

The electric light is being experimented with at present as an illuminating medium for coal workings. The great difficulty in fiery mines being the risk of explosion arising from lights, it becomes an important matter to devise methods to meet this danger.

The Davy lamp does not emit a strong light; hence if it can be proved that the electric light will not set fire to the inflammable gases of the mines in the event of accidental breakage of the protecting glass globes, its intense light should prove very valuable to the miner.

It has been found by experiment that the presence of coal dust in the workings contributes much to the risk of explosions; and it seems certain that if 3 per cent. of gas exists in the air of a mine which is thoroughly mixed with coal dust, an explosive mixture is formed. Mines should have at least two shafts, one of which serves to admit the pure air, while the foul gases escape by the other. The ascent of these gases is facilitated by creating a draught by means of a furnace at the bottom of one of the shafts or by fans driven at a high speed placed at top. This shaft is called the upcast shaft; the downcast shaft, which may be within a few yards of the other, allows the fresh air to pass down to the workings, to the faces of which it is directed by partitions of wood or canvas called "brattices." The air in its circuit below will travel several miles.

The coal lies in parallel layers, between which the gas exists in a highly compressed state. In order to detach these layers with the least possible danger, it is usual to cut through them endways, by which means the gas is allowed to make its escape at once from a considerable portion of the coal. From observation of some mines it is seen that discharge of fire-damp, though governed by atmospheric pressure, takes place before being indicated by the barometer, so that, as an indicator, that instrument cannot be relied on. As before said, the explosion of "fire-damp" in a mine results in an accumulation of the dangerous "after-damp,"[1] and more lives are lost by it than by the explosion itself. It has the appearance of a dense misty vapour, and resists the application of ventilation in an extraordinary manner. It benumbs the faculties and deprives the miner of all presence of mind, so that, instead of rushing at once to the pit bottom, if he has escaped the fire, he gets bewildered, and a deadly lethargy comes over him, ending in sleep from which he never awakes. It is rare to find choke-damp and fire-damp in the same workings, or if they do occur it is only in small quantities.

[1] A mixture of carbonic acid and other products of the combustion of the carburetted hydrogen.

The only effectual means of preventing accidents from these gases is a complete system of ventilation by air-courses through the mine. This ventilation is maintained either by the natural heat of the mine; by mechanical appliances, as pumps, fans, or pneumatic screws—either forcing air into the downcast shaft or exhausting it from the upcast shaft, by water falling constantly down the downcast, or by furnaces placed at the bottom of the upcast. Formerly furnace ventilation was considered to be the most efficient and reliable mode of ventilating very deep pits. The distance of the furnace from the bottom of the upcast shaft is a point of importance, 30 to 40 yards being a common distance.

The fans used for ventilation may be divided into two kinds,

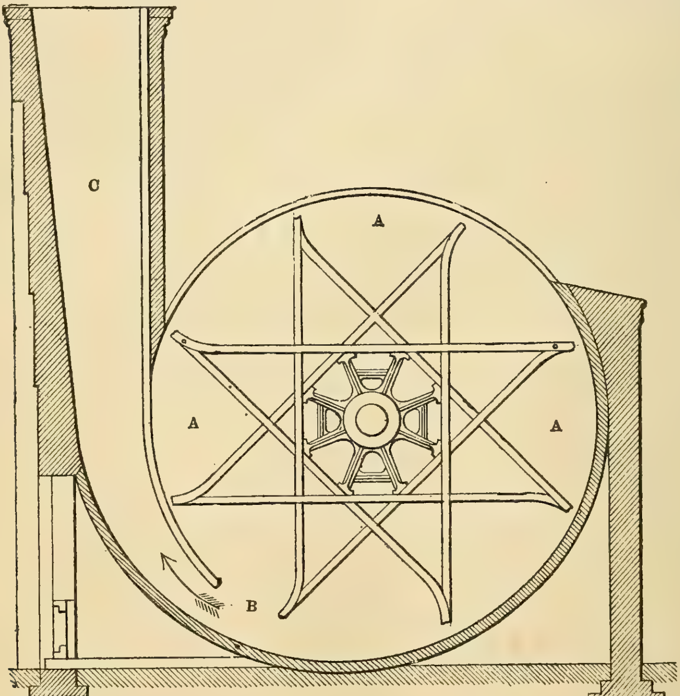


Fig. 1.—Side Elevation of Guibal Fan. A A, Rotating Fan. B, Discharge Orifice. C, Outlet.

viz. pump and centrifugal. In the first class are the Struvé, Nixon, Lemielle, and Roots; and in the second class the Guibal, Rammell, Waddle, and Schielé. Mechanical ventilators of the fan description appear in some cases to effect a saving of about 50 per cent.

over the furnace system, and the useful effect of a good fan seems to be from 40 to 60 per cent. of the power employed. The quantity of air discharged varies with the size of the fan and the speed of rotation. In some of the centrifugal fans of about 16 feet diameter, the quantity of air in cubic feet per minute passed amounts to from 40,000 to 50,000, and in larger fans of 30 to 50 feet diameter, 100,000 to 200,000 cubic feet per minute may be discharged. In the Schielé fan the speed is very high, 150 to 300 revolutions per minute, the diameter being smaller than some of the other forms, such as the Guibal, which is generally of a larger diameter with a less velocity of rotation, say about 90 revolutions per minute. An engraving of the Guibal fan, which is now largely used, is shown in Fig. 1.

As a general rule no mine should have a ventilating power of less than 100 cubic feet per minute for each man and boy employed in the underground passages, and in mines making large quantities of fire-damp a ventilation equal to from 200 to 600 cubic feet per minute per man should be attained.

The common methods of working coal in this country are "long-wall" and "stall and pillars," with a modification of the latter called "rances." By the "long-wall" system all the coal is excavated, and it is the most profitable way of working. Before starting any coal "long-wall," however, there are several circumstances to be considered, such as the nature of the roof, the property that might be injured by the subsidence of the superincumbent strata, and so on. In the "stall and pillar" system there is a great sacrifice of coal, generally about one-third, but often nearly one-half; this plan, therefore, should never be adopted if the coal can be worked "long-wall." Pillars are often left large or worked in "rances," with the intention of being afterwards removed; but this plan does not always succeed. Large as the pillars may be, they often sink into the pavement if it is soft, and cause a "creep," which shatters the coal, besides forcing the soft pavement up to the roof in the roads and rooms or stalls, and the contemplated removal of the pillars is thus frustrated. The edge seams of coal are worked "long-wall" in some cases, and "stall and pillar" in others. Instead of the pits being sunk straight down, inclined shafts are driven through the bed of coal, with rooms branching off from either side of the incline, and to work these the men stand on the coal as a floor, having the coal also as the roof. In the shaft, instead of a cage and slides, there is

a tramway, with trucks capable of holding two hutches or small waggons in each, the tramways being laid double in order to balance the engine, one truck ascending and the other descending, as in ordinary vertical shafts. These trucks have likewise boxes fitted for drawing the water, the mechanism for doing so being self-acting.

The method now universally adopted for bringing the coal to the surface is by a steam-engine having a drum on which the wire ropes are wound, the drum being sheathed with wood; the cages or frames for holding the hutches or small waggons being attached to the other end of the wire ropes, which are so arranged that one cage is descending with an empty hutch, and the other ascending with a hutch full of coal, the men descending and ascending in like manner. The shaft has a central division all the way down, formed of timber, to which are attached balks of the same material; balks are also fixed to each side of the shaft, to form a guide for the cages, the cage or iron frame having guiding pieces fitted to it. Many ingenious devices have been adopted to disconnect the cage from the rope in case of over-winding, or to prevent the cage from being dashed to the bottom should the rope snap. All these plans consist of mechanical contrivances, such as wedges, clips, eccentrics, serrated and arranged with springs and levers, so as instantly to grip the guides in the pit, and thus sustain the cage until the defects are made good. On the engine shaft is fitted a worm wheel and pinion, with an index, so that the engine tenter—who should always be on the look out, as this index is intended to point out the approach of the cage either way—knows when to stop the engine at the top or bottom. All modern engines are fitted with the link motion for actuating the slide valve; thus the man in charge of the engine can stop and reverse instantly, and so prevent accidents from over-winding.

A variety of machines have been introduced for cutting and breaking down the coal, saving the practical miner much hard labour. These consist chiefly in an arrangement of a series of cutters, which are made to revolve by the action of compressed air or steam; and they answer in certain localities where the seams of coal are of great thickness, but in many cases the miner has to lie on his side and use the pick in that position. Machines do not answer well in thin seams, where, after the coal is broken down, the men have to push it out of their rooms with their feet.

The utilization of coal for raising steam has now been adopted for many years, and the steam-engine may be called a machine whereby the power stored in the coal may be rendered available for the performing of mechanical work.

The history of the steam-engine, like that of other important inventions, shows a slow and gradual development from comparatively simple and rude appliances to the highly finished and complex machine of the present day.

The earliest notice which we have of the use of steam is in the writings of Hero of Alexandria (B.C. 120), where a rotatory steam-engine is mentioned. In 1663 the Marquis of Worcester devised a steam-engine for pumping water, and in 1697 Savery applied steam to pump water out of mines. Papin in 1690 improved the earlier rude machine, and introduced the cylinder and piston. Newcomen in 1705 introduced the separate boiler, and through the alternate pressure and condensation of the steam produced the atmospheric pumping engine.

To James Watt, however, we must look as the inventor who brought the steam-engine to be a really serviceable machine for commercial purposes, and this mainly through his invention of the separate condenser, whereby the steam, instead of being condensed in the cylinder, as in Newcomen's engine, was conveyed to a separate vessel, where, by means of a jet of water, it became condensed and afterwards pumped out to be used as feed-water to the boiler.

Attempts were made from time to time to use the steam-engine as a propelling power for boats, and both in Europe and in America various experiments were made. To Fulton in America and Bell in this country, however, the credit of successfully introducing passenger steamers must be given.

The application of steam to locomotives was attempted by various engineers, but the successful introduction of the railway locomotive is mainly due to George Stephenson; the main elements of success being the adoption of the tubular boiler and forced blast. Steam has also been applied to road locomotive traction engines and agricultural machinery, and, of course, in the many forms of land engines it is still supreme.

BOILERS FOR STATIONARY ENGINES.

DISTINCTIVE FORMS OF BOILERS.

The common cylindrical boiler with hemispherical ends is extensively used for colliery engines and other places where space is no object, and the consumption of fuel but little thought of. For such purposes it is the simplest, and, as no stays are required, the strongest of its kind. It rests on a structure of brickwork, having the furnace underneath, with a return flue all round; the parts exposed to the action of the flame are lined with fire-brick. As there are usually no internal flues, it is obvious that it is a very safe boiler, having always a good body of water over the furnace, or fire-grate; but still it is not free from the rapid corrosion that sets in with all boilers resting on a substructure of brickwork. Sometimes boilers of this form have the front end quite flat, for the convenience of attaching the water gauge glass, steam-pressure gauge, &c.

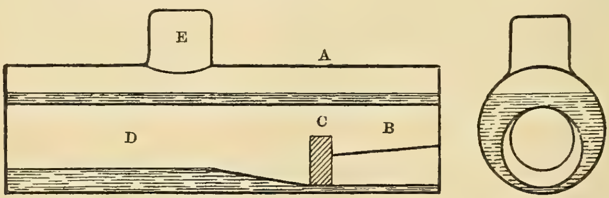


Fig. 2.—Cornish Boiler with Single Furnace. Longitudinal and Transverse Sections. A, Shell. B, Furnace. C, Fire-brick bridge. D. Flue. E, Steam dome.

The Cornish boiler differs materially from the plain cylindrical form: both the ends are quite flat, with one internal flue running through and through, and having the fire-grate at one end; or with one internal flue, and having the furnace underneath the boiler, with return flues in the usual manner. Another form has two internal furnaces, meeting in a combustion chamber. This plan of construction is well suited for the prevention of smoke; but to attain this end the furnaces should be fired alternately, so that one fire is quite bright, while the other one is green, or in the act of firing. To assist combustion, small tubes are introduced from the front end, passing through the water space into the combustion chamber. Thus a

current of heated air mixes with the flame and heated gases, and prevents smoke to a great extent. The simplicity of this arrangement cannot be excelled, as careful firing of itself will, in a great measure, prevent smoke, while the current of hot air, mixing with the heated gases in the furnace, largely contributes to the same result. The top parts of the ends are stayed with gusset pieces, connected to the top and ends of the boiler, and the combustion chamber is strengthened at the back of the furnace with one or more conical

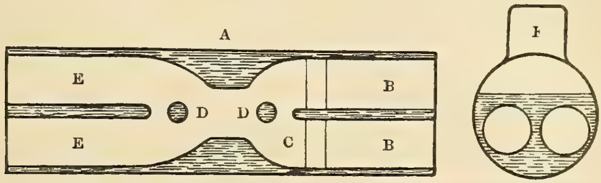


Fig. 3.—Boiler with Double Furnaces. Horizontal and Transverse Sections.
A, Shell. B B, Furnaces. C, Combustion chamber. D D, Stay tubes. E E, Flues. F, Steam dome.

tubes, with the water freely passing through them. As large flues are weak, sometimes they are strengthened with conical tubes at intervals; the back flue, in some cases, is divided into two smaller ones, and the conical tubes omitted, thus leaving the flues quite clear, so that they can be easily cleaned out. Another kind of

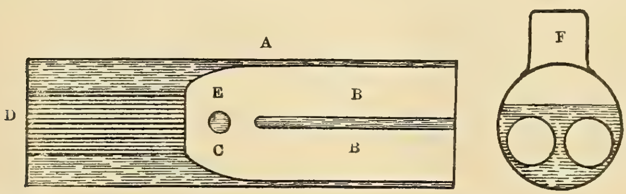


Fig. 4.—Combined Cornish and Multitubular Boiler. Horizontal and Transverse Sections.
A, Shell. B B, Furnaces. C, Combustion chamber. D, Small tubes. E, Stay tube. F, Steam dome.

cylindrical boiler has a number of small tubes set at the back of the combustion chamber, thus combining, in some respects, the Cornish with the multitubular arrangement. For low pressure steam, and where space is an object, and when deposits from the water are rapidly formed over the heating surface, a self-contained boiler, designed by the author, has done good service. It is fitted with one round furnace, carrying the flame and heated gases to the back, returning to the front end through large tubes, 8 inches in diameter, and then repassing to the back through other

tubes of the same diameter; then down at the back, and along the sides and bottom, through suitable flues of brickwork, so that, internally and externally, a large amount of heating surface is obtained, and this great desideratum is secured that all the tubes are easily got at for repairs and scaling off the deposits.

A, Shell. B, Furnace. C, Combustion chamber. D D, Tubes. E, Smoke-box. F, Flue.

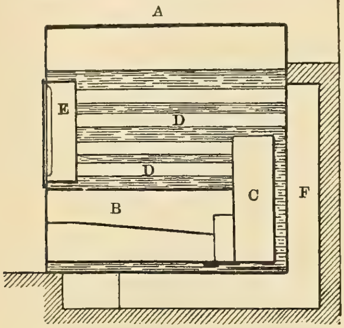


Fig. 5.—Return Tubular Boiler. Longitudinal Section.

Thus we have noticed arrangements partly self-contained, but having external flues of brickwork, such as are in general use. Next comes that class which is wholly self-contained, the heated gases, after doing duty in the boiler, simply going up the chimney. There are several arrangements having all the same object in view, namely, to economize space. By one of them an ordinary round shell has a square furnace fitted; the flame, after doing its best duty in the fire-box, passes through one or two large flues, crossed with a series of conical tube stays, and the flame interlacing, as it were,

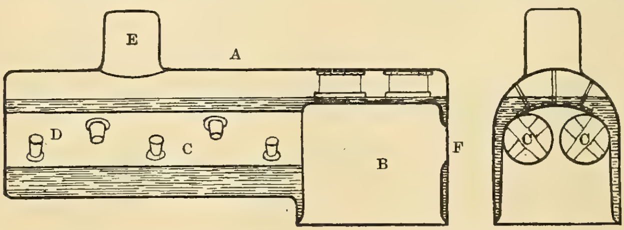


Fig. 6.—Self-contained Flue Boiler. Longitudinal and Transverse Sections.
A, Shell. B, Fire-box. C C, Flues. D, Stay tubes. E, Steam dome. F, Fire-door.

amongst them, makes a very effective arrangement, and in cases where the water, from its impure state, rapidly forms deposit, all the parts can easily be reached. Instead of the large flues, small tubes are sometimes arranged, as in the locomotive boiler, so that the useful caloric is extracted by honeycombing the water, as it were, with hundreds of square feet of heated surface; but when very small tubes are used, they should be of a different material from the boiler—brass, or composition tubes, are to be preferred—thus the incrustation is in a great measure prevented. Sometimes the fire-box is made cylindrical, having a hemispherical outside dome; by this

plan very few stays are required; the tube-plate, however, must be made flat, with the back of the outside fire-box to correspond, or as it were part of the cylindrical portion of the fire-box, cut away in the plan, that part having screwed stays in the usual manner. This arrangement has now become obsolete.

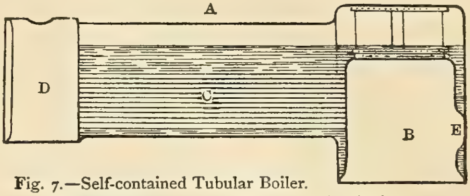


Fig. 7.—Self-contained Tubular Boiler.
A, Shell. B, Fire-box. C, Tubes. D, Smoke-box.
E, Fire-door.

Another form extensively used for general purposes is the vertical type. Such boilers are made entirely cylindrical; some are constructed with an internal barrel, with the smoke-pipe passing through the steam space; while

A, Shell. C, Smoke-pipe.
B, Fire-box. D, Fire-door.

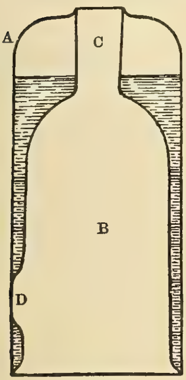


Fig. 8.
Vertical Dome Boiler.

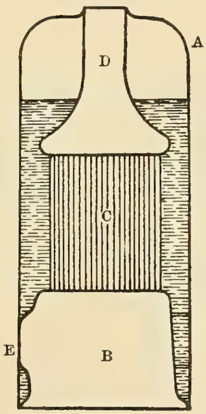


Fig. 9.
Vertical Tubular Boiler.

Fig. 9.
A, Shell.
B, Fire-box.
C, Tubes.
D, Smoke-pipe.
E, Fire-door.

Fig. 10.
A, Shell.
B, Fire-box.
C C, Flues.
D, Fire-door.

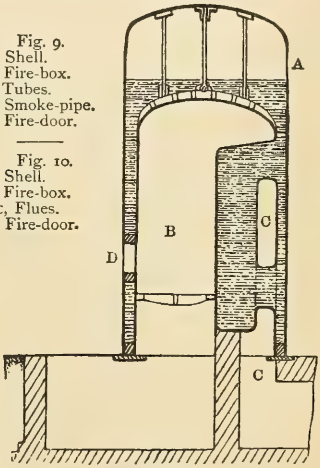


Fig. 10.
Vertical Return Boiler.

some steam generators of this kind are made very lofty, fitted with an internal cone fire-box, and arranged in communication with the waste heat from puddling and other furnaces, &c., and others for general purposes have small tubes placed vertically, arranged with the smoke-box underneath the water, and the smoke-pipe passing through the steam space. Other arrangements have the tubes passing to the top of the boiler, with a dry uptake; thus the tubes can easily be inspected without disturbing the steam-tight portions of the boiler; and the tubes are easily cleaned by simply taking off the dry uptake, or lower portion of the funnel. The boiler-tubes

of a steam carriage for common roads having become foul with soot, thus impeding the draught, gunpowder was wrapped up tightly in a piece of paper and thrown on the fire, and the fire-box door immediately shut; a slight explosion took place, sending a cloud of soot up the chimney, effectually clearing the tubes without stopping the machine. Of course, it would be somewhat dangerous to carry an explosive mixture about for such a purpose; but, in most cases, this means of clearing the tubes can be cheaply and most effectually carried out, and there is no danger whatever, provided too much gunpowder is not used at once. All vertical self-contained boilers should have air tubes ¾ inch in diameter, and spaced about 6 inches apart, all round the fire-box, dipping downwards, so that a current of air may mix with the flame and heated gases at about the level of the top of the fuel, thus tending to the prevention of smoke; these tubes are screwed into the outside shell and the inside fire-box, and then rivetted over.

There is one objection common to all vertical boilers, namely, that a great portion of the heat passes directly up the chimney without doing duty; to obviate this defect the flame and heated gases are directed downwards with suitable flues; this plan must have separate flues of fire-brick, with a chimney, and is not so compact an arrangement as the multitubular one. The feed-water pipe passes through the bottom flues, thus heating the water in its passage to the boiler, and all the flues are easily reached for scaling and cleaning out.

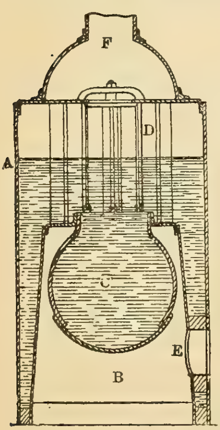


Fig. 11.—Pot Boiler. A, Shell. B, Fire-box. C, Pot. D, Tubes. E, Fire-door. F, Smoke-pipe.

The pot boiler derives its name from the peculiar pot-like vessel, fitted to, and hanging from the top of the fire-box; this spherical generator is introduced so that the lower part, made of copper, receives the full benefit of the flame; the annular space between the pot and the fire-box is made narrow, thus the flame and heated gases impinge against the sides of the fire-box, and then pass through the small tubes into the chimney. The ebullition of the water in the pot is very violent, ejecting the sediment and preventing incrustation; the deposit finds its way to the bottom of the boiler, and is cleaned out by suitable sludge doors. The dry uptake can be easily removed, and the inside of the boiler inspected through the man-hole, placed exactly over the pot, in the

centre of the boiler, there being no tubes at the centre, but merely all round the opening in the top of the pot, which is bolted to the tube-plate by means of projecting flanges on the pot and tube-plate.

In some cases, such as in the Fire-engine, it is a desideratum to have a rapid steam-producing boiler; a good example is simply an ordinary vertical boiler, having the tubes suspended inside of the fire-box, arranged with an internal tube in each, loosely supported from the tube-plate, these small inside tubes leaving annular spaces between them and the larger tubes, so that only a thin film of water is exposed to the heating surface. By this means steam is raised rapidly; but it must be borne in mind that, as the evaporation of the water is very great, care must be taken that a sufficient quantity of water is kept up in the boiler, which would otherwise soon boil dry. The circulation is very rapid in the tubes. The bottoms of the tubes are hermetically sealed; and as the steam is generated, it ascends, displacing the water in the annular space between the inner and outer tubes, and the water from the top circulates down the inner tubes and fills up the cavity. The smoke-pipe is connected to the top of the fire-box, passing through the steam space, and is rivetted to an angle-iron ring on the top of the boiler; and there is an open part left in the centre of the fire-box where there are no tubes, this opening being blocked up with a lump of fire-brick suspended by a rod from the top of the boiler, thus the flame is prevented from going directly up the chimney, as it impinges against the fire-clay lump, and by this means it is distributed beneficially amongst the small tubes.

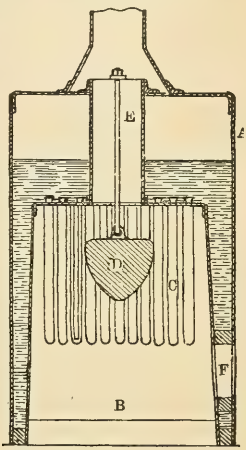


Fig. 12.—Boiler with Suspended Annular Tubes. A, Shell. B, Fire-box. C, Tubes. D, Fire-brick lump. E, Smoke-pipe. F, Fire-door

Instead of a number of annular tubes, one large tube has been successfully adopted, the arrangement consisting of an internal fire-box, having an annular[1] water space all round. On the outside of this water space there is an annular flue, and the whole is contained in an ordinary vertical boiler, having a hemispherical top; the flame and the gases, after doing duty in the fire-box, find their way

[1] The space between a small inner and large outer tube is called annular.

through an opening into the annular flue, and then escape all round into a flue of brickwork; thus a large heating surface is obtained. As in the pot boiler, there is great ebullition in the annular space around the inside fire-box, the steam escaping into the boiler proper through a tube at the top, the circulation of the water being effected by a series of small tubes, connecting the inside and the outside water spaces at the bottom of the boiler.

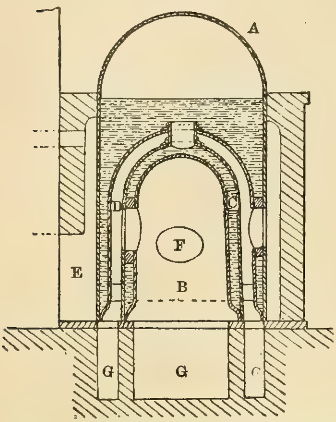


Fig. 13.—Annular Boiler. A, Shell. B, Fire-box. C, Annular water space. D, Annular flue. E, Flue. F, Fire-door. G, Ash-pit.

What are termed "water-tube" boilers show examples consisting merely of large tubes, so connected as to form a series of boilers, the whole being encased in brickwork. This species of steam generator is capable of sustaining great pressure, the whole of the steam pipes and the connections being tested to about 500 lbs. per square inch; and as they are constructed so that all the joints are protected from the action of the flame, they ought to be very durable. Where space is no object they are well suited for small powers, but for large power it is doubtful if they are so well adapted as the ordinary Cornish arrangements, fitted with conical water tubes in the flues.

One arrangement of the water-tube boiler consists of a series of tubes 4 feet 6 inches long and 7 inches in diameter, closed at the upper ends, having plates ½ inch in thickness welded in, and round the bottom ends heavy cast-iron rings with lugs are fixed. The ends of the tubes are roughened, and the rings are cast on, thus the contraction of the cast-iron, as well as a partial uniting of the two metals, render this mode of fastening on the rings a very secure one; the tubes are arranged in transverse rows in an oven, between the furnace and the chimney. The lower ends of the tubes for each row are united to a pipe 10 inches in diameter, and of suitable thickness, which is strengthened by diaphragm plates cast in, and perforated with small holes. On this pipe short branch pieces are cast, which are turned and recessed, for the reception of the ends of the other tubes, to which they are strongly united by means of bolts and gun-metal nuts, recessed into the lugs, the rings on the tubes having

corresponding lugs. The joint is made with a composition ring, of lead and tin, dropped into the recess, and then the screws are tightened; this joint is capable of sustaining as great a pressure as the tubes, and can be made and re-made at any time without injury.

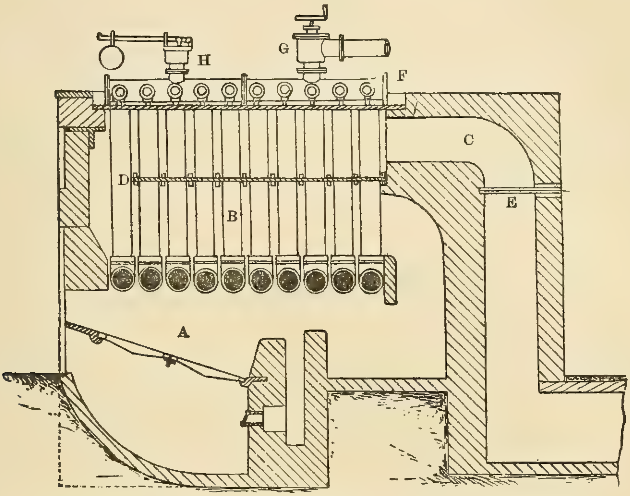


Fig. 14.—Water-tube Boiler. A, Furnace. B, Tubes. C, Flue. D, Division plate. E, Damper. F, Steam receiver. G, Stop valve. H, Safety valve.

The upper ends of the tubes have short pieces of wrought-iron welded gas pipe, tapped into the end plates, for taking away the steam to the main pipe, which is placed horizontally. Upon the main steam pipe smaller pipes are fitted, and connected to the small gas pipes from each generator; thus the steam flows along them into the large pipe, to which is fixed the safety-valve and the pipe to the steam cylinder. All the parts are so arranged that they can expand freely, without disturbing the joints. The oven has a division plate strongly ribbed; by this means the flame impinges on the bottom halves of the generators, and passing along the top half goes to the chimney.

Another arrangement of water-tube generators has simply wrought-iron tubes, with cast-iron ends, secured with long bolts inside of the tubes, having the feed pipes joining together at the bottom; similar pipes are situated at the top of the tubes for the steam, these lead into one main steam pipe, the whole being encased in suitable brickwork. All the parts in this arrangement are well protected, only the plain parts of the tubes being exposed

to the action of the flame; the bottom joints are embedded in the brickwork, and each of the tubes exposes an area of 16 feet,

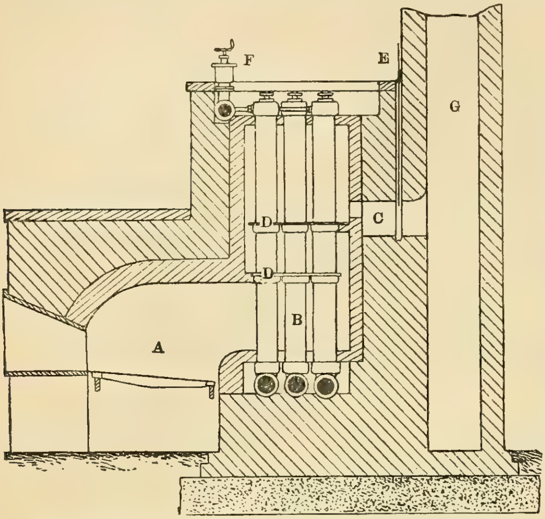
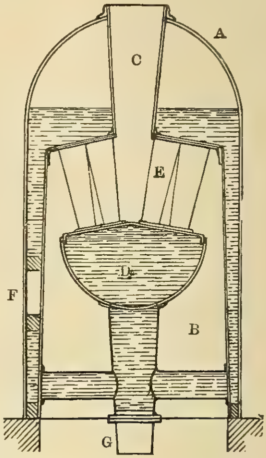


Fig. 15.—Water-tube Boiler. A, Furnace. B, Tubes. C, Flue. D D, Division plates. E, Damper. F, Stop valve. G, Chimney.



A, Shell. B, Fire-box. C, Smoke-pipe. D, Circulating water space. E, Conical tubes. F, Fire-door. G, Sludge cap

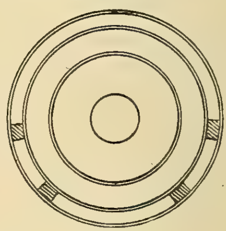


Fig. 16.—Self-contained Water-tube Boiler.

equal to one horse-power. This arrangement is certainly very simple, and is to be commended, provided the expansion of the long bolts does not affect the caps at the ends, causing steam to blow at the joints. These water-tube boilers must be so manufactured that no destructive expansion may be allowed to take place, and all the joints should be metal to metal where practicable.

Water-tube boilers, sometimes called tubulous, may be of various forms. The water tubes can be arranged in a variety of ways, so that the furnaces, the tubes, and the shell are self-contained. Thus to an ordinary vertical boiler an inside fire-box is fitted, as likewise a pot-shaped vessel connected by circulating pipes with the shell, as shown by Figs. 15 and 16. A current of water is continually descending between the fire-box and the outside shell, and finds its way into the pot through the circulating pipes at the bottom. These boilers keep free from deposit, owing to the rapid circulation, and for some purposes are recommended to be arranged with conical or common tubes.

In the Perkins system of boiler a large number of water tubes are enclosed in a double shell of plate iron, the space being filled with a non-conducting medium. The tubes are $2\frac{1}{4}$ inches inside diameter and $\frac{3}{8}$ inch thick. About one half of the tubes are used for generating steam, the other half being used for superheating. The boiler is supplied with distilled water, and the furnace is placed beneath the tubes which run vertically above. Tubulous boilers have been tried at sea in the *Propontis* and other vessels on Rowan's system, and again recently in the steam yacht *Anthracite*, which lately made a voyage across the Atlantic and back, carrying a pressure of from 300 to 500 lbs. of steam per square inch. This vessel was fitted with the Perkins boiler.

ON BOILERS, BY FAIRBAIRN.

We propose under this head to consider the steam-boiler in its construction, management, security, and economy.

As regards the construction, it is absolutely necessary to study carefully the shapes which give maximum strength, and require minimum of material. In boilers this is most important, as any increase in the thickness of the plate obstructs the transmission of heat, and exposes them as well as the rivets to injury on the side exposed to the action of the flame. It has been generally supposed that the rolling of boiler plates gives to the sheets greater tenacity in the direction of their length than in that of their breadth. This is, however, not always the case, as experiments show that the tensile strain across the fibre of boiler plates is in some samples greater than their tensile strength when torn asunder in the direction of the fibre. We consider this may be owing to the way the iron is piled before putting it through the rolls; more recent experiments plainly show that the tensile strength of boiler plates is slightly greater in the direction of the fibre, and from this it would appear that although it is more convenient to construct circular boilers, with plates rolled in the direction of the fibre, still we think that boilers diagonally plated are the strongest.

Next to the tenacity of the plates comes the question of rivetting. On this point we have been widely astray, and it required some skill, and no inconsiderable attention in conducting the experiments, to convince even some practical men that the rivetted joints were not stronger than the plate itself. In punching holes along the edge of a plate, it is obvious that the plates must be

weakened to the extent of the sectional area punched out; and it is found also that the metal between the holes is deteriorated by the process of punching.[1] This deteriorating result was clearly demonstrated by a series of experiments which took place some years ago, and in which the strength of almost every description of rivetted joints was determined by tearing each directly asunder. The results obtained from these experiments were conclusive as regards the relative strength of rivetted joints and the solid plates. In two different kinds of joints, double and single rivetted, the strength was found to be in the ratio of 100 for the solid plate, 70 was the strength of a double-rivetted joint after allowing for the adhesion of the surfaces of the plates, and 56 was the strength of a single-rivetted joint. These proportions of relative strength of plates and joints may therefore in practice be safely taken as the standard value in the construction of vessels required to be steam and water tight, and subjected to pressure varying from 10 lbs. to 100 lbs. on the square inch.

The following is the rule for proportions as given by Professor Rankine:[2]—

"Let r denote the radius of a thin hollow cylinder, such as the shell of a high-pressure boiler; t, the thickness of the shell; f, the tenacity of the material in lbs. per square inch; p, the intensity of the pressure in lbs. per square inch required to burst the shell. This ought to be taken at SIX TIMES the effective working pressure, then $p = \frac{ft}{r}$, and the proper proportion of thickness to radius is given by the formula $\frac{t}{r} = \frac{p}{f}$."

"The following formula gives approximately the *collapsing pressure* p in lbs. on the square inch of a plate iron flue, whose length l, diameter d, and thickness t, are all expressed *in the same* units *of measure*: $p = 9{,}672{,}000 \frac{t^2}{ld}$."

"Tenacity of wrought-iron plates = 51,000 lbs. per square inch.
Tenacity of wrought-iron joints, double rivetted = 35,700 lbs. per square inch.
Tenacity of wrought-iron joints, single rivetted = 28,600 lbs. per square inch."

In the construction of boilers exposed to severe internal pressure, it is desirable to adopt such forms, and so to dispose the material, as to apply the greatest strength in the direction of the greatest

[1] In the best modern practice, therefore, all rivet holes are drilled where practicable.
[2] See *Manual of the Steam Engine.*

strain. Professor W. R. Johnson, of the Franklin Institute of America, whose inquiries into the strength of cylindrical boilers are of great value, may be quoted as an authority:—

"1st. To know the force which tends to burst a cylindrical boiler in the longitudinal direction, or, in other words, to separate the *head* from the curved *sides*, we have only to consider the actual area of the head, and to multiply the units of *surface* by the number of units of *force*, applied to each superficial unit, this will give the total *divellent*. To counteract this, we have, or may be conceived to have, the tenacity of as many longitudinal bars as there are units in the circumference of the cylinder. The united strength of these bars constitutes the total retaining or quiescent force, and at the moment when rupture is about to take place the divellent and quiescent forces must obviously be equal.

"2d. To ascertain the amount of force which tends to rupture the cylinder along the curved side, or rather along the opposite sides, we may consider the pressure as applied through the whole breadth of the cylinder upon each lineal unit of diameter. Hence the total amount of force which would tend to divide the cylinder in halves, by separating it along two lines of opposite sides, would be represented by multiplying the diameter by the force exerted on each unit of surface, and this product by the length of the cylinder. But even without regarding the length, we may consider the force requisite to rupture a *single band* in the direction now supposed, and of one lineal foot in *breadth*, since it obviously makes no difference whether the cylinder be long or short, in respect to the ease or difficulty of separating the sides. When the diameter of a boiler is increased, it must be borne in mind that the area of the ends is also increased, not in the ratio of the diameter, but in the ratio of the square of the diameter; and it will be seen, that instead of the force being doubled, as in the case of the direction of the diameter and circumference, it is quadrupled upon the ends, or, what is the same thing, a cylinder double the diameter of another cylinder, has four times the pressure in the longitudinal direction. The retaining force, or the thickness of metal of a cylindrical boiler, does not, however, increase in the same ratio as the area of the circle, but simply in the ratio of the diameter, consequently the thickness of the metal will require to be increased in the same ratio as the diameter is increased. From this it appears that the tendency to rupture, by blowing out the ends of a cylindrical boiler, will not be greater in this direction than it is in any other

direction; we may therefore safely conclude, since we have seen that the tendency to rupture increases in both directions in the ratio of the diameter, that any deviation from that law, as regards the thickness of the plates, would not increase the strength of the boiler."

We have been led to the following inquiries from the circumstance that Mr. Johnson appears to reason on the supposition that there are no joints in the plates, and that the tenacity of the iron is equal to 60,000 lbs., rather more than 26 tons, to the square inch. Now the result of experiment has shown that ordinary boiler plates will not bear more than 23 tons to the square inch; and as nearly one-third of the material is punched out for the reception of the rivets, we must still further reduce the strength, and take 15 tons, or about 34,000 lbs., on the square inch, as the tenacity of the boiler plates, or the pressure at which the boiler would burst. By experiment it has been found that the strength of the single-rivetted joints of boilers is little more than half the strength of the plate itself; but taking into consideration the crossing of the joints, 34,000 lbs. may reasonably be taken as the tenacity of the rivetted plates, or the bursting pressure of a cylindrical boiler.

It has been stated that the strength of cylindrical boilers, when taken in the direction of their circumference, is in the ratio of their diameters, and when taken in the direction of the ends, as the squares of the diameters; a proposition which it will be difficult to demonstrate as applicable to every description of boiler of the cylindrical form. It will be seen, however, that the strain is not exactly the same in every direction, and that there is actually less upon the material in the longitudinal direction than there is upon the circumference. For example, let us take two boilers, one 3 feet in diameter and the other 6 feet in diameter, and suppose each to be subjected to a pressure of 40 lbs. to the square inch. In this condition, it is evident that the area, or number of square inches, in the end of the 3 feet boiler is to that of the area of the 6 feet boiler as 1 to 4; and, by a common process of arithmetic, it is found that the edges of the plates forming the cylindrical part of the 3 feet boiler is subject, at 40 lbs. on the square inch, to a pressure of 40,714 lbs., or upwards of 18 tons; whereas the plates of a 6 feet boiler have to sustain a pressure of 162,856 lbs., or 72 tons, which is quadruple the force to which the boiler only one-half of the diameter is exposed; and the circumference being only as 2 to 1, there is necessarily double the strain upon

the cylindrical plates of the large boiler. Now this is not the case with the other parts of the boiler, as the circumference of a cylinder increases only in the ratio of the diameter, consequently the pressure instead of being increased in the ratio of the squares of the diameter, as shown in the ends, is only doubled, the circumference of the 6 feet boiler being twice that of the 3 feet boiler.

Let us, for the sake of illustration, suppose the two cylindrical boilers such as we have described to be divided into a series of hoops of 1 inch width, and taking one of these hoops in the 3 feet boiler, we shall find it exposed at a pressure of 40 lbs. on the square inch to a force of 1440 acting on each side of a line drawn through the axis of a cylinder 36 inches diameter and 1 inch in depth, and which line forms the diameter of the circle. Now this force causes a strain tending to burst the hoops in the 3 feet circle of 720 lbs., and assuming the pressure to be increased until the force becomes equal to the tenacity or retaining power of the material, it is evident, in this state of the equilibrium of the two forces, that the preponderance on the side of the internal pressure would insure fracture; and supposing we take the plates of which the boiler is composed, of one quarter of an inch thick, and the ultimate strength at 34,000 lbs. on the square inch, we shall have $\frac{34000}{36 \times 2} = 472$ lbs. per square inch, as the bursting pressure of the boiler. Again, as the forces in this direction are not as the squares, but simply as the diameters, it is clear that at 40 lbs. on the square inch we have in a hoop an inch in depth, or that portion of a cylinder whose diameter is 6 feet, exactly double the force applied to rend the iron asunder, as in the 3 feet boiler. Now, assuming the plates to be quarter of an inch thick, as in the 3 feet boiler, it follows, if the forces at the same pressure be doubled in the large cylinder, that the thickness of the plates must also be doubled, in order to sustain the same pressure with equal security; or, what is the same thing, the 6 feet boiler must be worked at half the pressure, in order to secure the same degree of safety as attained in the 3 feet boiler at the given pressure. From these facts it may be useful to know that boilers having increased dimensions, should also have increased strength in the ratio of their diameters; or, in other words, the plates of a 6 feet boiler should be double the thickness of the plates of a 3 feet boiler, and so on as the diameter increases.

The relative powers of force applied to cylinders of different diameters become more strikingly apparent when we reduce them to their equivalents of strain per square inch, as applied to the ends

and circumference of the boiler respectively. In the 3 feet boiler, working at 40 lbs. pressure, we have a force equal to 720 lbs. upon an inch width of plates, and one quarter of an inch thick, or $720 \times 4 =$ 2880 lbs., the force per square inch upon every point of the circumference of the boiler. Let us now compare this with the actual strength of the rivetted plates themselves, which, taken as before at 34,000 lbs. on the square inch, gives the ratio of the pressure as applied to the strength of the circumference as 2880 to 34,000, nearly as 1 to 12, or 472 lbs. per square inch as the ultimate strength of the rivetted plates.

These deductions appear to be true in every case as regards the resisting powers of cylindrical boilers to a force radiating in every direction from its axis towards the circumference; but the same reasoning is, however, not maintained when applied to the ends, or, to speak technically, to the angle-iron, and rivetting, when the ends are attached to the circumference. Now, to prove this, let us take the 3 feet boiler, where we have 113 inches in the circumference, and upon this circular line of connection we have, at 40 lbs. to the square inch, to sustain a pressure of 18 tons, which is equal to a strain of 360 lbs. acting longitudinally upon every inch of the circumference. Apply the same force to the 6 feet boiler, with a circumference or line of connection equal to 226 inches, and we shall find it exposed to exactly four times the force, or 72 tons; but in this case it must be borne in mind that the circumference is doubled, and consequently the strain, instead of being quadrupled, is only doubled on a force equal to 720 lbs., acting longitudinally as before upon every square inch of the circumference of the boiler. From these facts we come to the conclusion that the strength of cylindrical boilers is in the ratio of their diameters, if taken in the line of curvature, and as the squares of the diameters as applied to the ends or their sectional area; and that all descriptions of cylindrical tubes, to bear the same pressure, must be increased in strength in the direction of their circumferences, simply as their diameters, and in the direction of the ends as the squares of the diameters.

Again, if we refer to the comparative merits of the plates composing cylindrical vessels, subjected to internal pressure, they will be found in the anomalous condition, that the strength in their longitudinal direction is twice that of the plates in the curvilinear direction. This appears by a comparison of the two forces, wherein

we have shown that the ends of the 3 feet boiler, at 40 lbs. internal pressure, sustain 360 lbs. of longitudinal strain upon each inch of a plate a quarter of an inch thick; whereas the same thickness of plates have to bear, in the curvilinear direction, a strain of 720 lbs. This difference of strain is a difficulty not easily overcome; and all that we can accomplish in this case will be to exercise a sound judgment in crossing the joints, in the quality of the workmanship, and in the distribution of the material. For the attainment of these objects, the following table, which exhibits the proportionate strength of cylindrical boilers from 3 to 8 feet, may be useful:—

Diameters of Boilers.		Bursting Pressure equivalent to the ultimate strength of the Rivetted Joints, as deduced from experiment. 34,000 lbs. to the square inch.	Thickness of the Plates in decimal parts of an inch.
Feet.	Inches.		
3	0		·250
3	6		·291
4	0		·333
4	6		·376
5	0		·416
5	6	450 lbs.	·458
6	0		·500
6	6		·541
7	0		·583
7	6		·625
8	0		·666

Boilers of the simple form, and without internal flues, are subjected only to one species of strain; but those constructed with internal flues are exposed to the same tensile force which pervades the simple form; and farther, to the force of compression, which tends to collapse or crush the material of the internal flues.

From the existing state of our knowledge we must rest satisfied that the flues of ordinary boilers can be materially strengthened by the introduction of iron hoops, but we are of opinion they should never be introduced where deposits rapidly form, such as in marine boilers, &c.; for it must be borne in mind that there are two thicknesses of material at the parts hooped, and the incrustation that forms proves highly detrimental to the furnaces. In many cases where deposits have formed at the hoops the furnace-plates have bulged out very much.

Fairbairn gives a table of internal flues fitted with T-iron or angle-iron hoops. The length of the flues must be measured between the rigid supports; in an unsupported flue, as ordinarily constructed,

the length is measured between the end plates of the boiler. In the flues as proposed, between the T-iron ribs, the dimensions given are for a collapsing pressure of 450 lbs. per square inch; the safe working pressure should be 75 lbs. per square inch.

Diameter of Flues in inches.		Thickness of Plates.		
		10 Feet Long.	20 Feet Long.	30 Feet Long.
12		·291	·399	·480
18		·350	·480	·578
24		·399	·548	·659
30	450 lbs.	·442	·607	·730
36		·480	·659	·794
42		·516	·707	·851
48		·548	·752	·905

The above are founded on the supposition that the 20-feet and 30-feet long flues have T-iron or angle-iron hoops at the necessary joints, the hoops to be placed 10 feet apart. Some makers prefer placing the T-iron hoops at each joint, the plates butting on one another, and at the longitudinal joints likewise.[1] When the joints are planed, and the butt strips properly fitted, the strain is entirely taken off the rivets, the compressive strain being taken on the ends of the plates directly.


Fig. 17.—Rolled Hoop.

In the cylindrical boiler, with round flues, the forces are diverging from the central axis as regards the outer shell, and converging as applied to every separate flue which the boiler contains. To show the amount of strain upon a high-pressure boiler 30 feet long and 6 feet in diameter, having two centre flues, each 2 feet 3 inches diameter, working at a pressure of 50 lbs. on the square inch, we have only to multiply the number of square feet of surface—1030 exposed to pressure—by 3·21, and we have the force of 3306 tons which a boiler of these dimensions has to sustain. We mention this to show that the statistics of pressure, when worked out, are not only curious in themselves, but instructive as regards a knowledge of the retaining powers of vessels so extensively used.

[1] These T-hoops are now almost superseded by rings shaped as above (Fig. 17), and rolled specially for the purpose. The latter answer admirably, and also allow of expansion and contraction.

To pursue the subject a little further, let us suppose the pressure to be 450 lbs. on the square inch, which a well-constructed boiler of this description will bear before it bursts, and we have the enormous force of 29,754 tons, or nearly 30,000 tons, compressed within a cylinder 30 feet long and 6 feet diameter. This is, however, inconsiderable when compared with the locomotive and some marine boilers, which, from the number of tubes they contain, present a much larger surface to pressure. Locomotive boiler engines are usually worked at 120 lbs. on the square inch; and taking one of the usual construction we shall find that it rushes forward on the rail with a pent-up force within its interior of nearly 60,000 tons, which is rather increased than diminished at an accelerated speed. In a stationary boiler, charged with steam at a given pressure, it is evident that the forces are in equilibrium, and the strain being the same in all directions, there will be no tendency to motion. Supposing, however, this equilibrium to be destroyed, by accumulative pressure, till rupture ensues, it follows that the forces in one direction having ceased, the others in an opposite direction, being active, would project the boiler from its seat with a force equal to that which is discharged through the orifice of rupture. The direction of motion would depend upon the position of the ruptured part: if in the line of the centre of gravity, motion would ensue in that direction; if out of that line, an oblique or rotatory motion round the centre of gravity would be the result. (An explosion of a plain vertical boiler may be taken as an example: it gave way at the bottom of the fire-box or bottom of the boiler, and by the reactive force of the steam it was lifted about 100 feet in the air like a sky-rocket, and when the force was spent, and the water and the steam expelled, it descended, landing on the identical spot where it had rested previous to the explosion.) The momentum or quantity of motion produced in one direction would be equal to the intensity or quantity lost; and the velocity with which the body would move would be in the ratio of the impulsive force, or the quantity lost. Therefore, the quantity of motion gained by an exploded boiler in one direction will be as the weight and quantity lost in that direction. These definitions, however, belong more to the province of the mathematician, and may be easily computed from well-known formulæ on the laws of motion.

The following table shows the bursting pressure of boilers, as likewise the safe working pressure, as deduced from experiment,

with a strain of 34,000 lbs. on the square inch as the ultimate strength of rivetted joints:—

Diameter of Boiler.	Working Pressure for ⅜-inch Plates.	Bursting Pressure for ⅜-inch Plates.	Working Pressure for ½-inch Plates.	Bursting Pressure for ½-inch Plates.
ft. in.				
3 0	118	708¼	157¼	944¼
3 3	109	653¾	145¼	871¾
3 6	101	607	134¾	809½
3 9	94½	566½	125¾	755½
4 0	98½	531	118	708¼
4 3	83¼	500	111	666½
4 6	78¾	472	104¾	629½
4 9	74½	447½	99½	596¼
5 0	70¾	425	94¼	566½
5 3	67¾	404¾	83¾	515
5 6	64¾	386¼	82	492¾
5 9	61½	369½	78¾	472
6 0	59	354	75½	453¼
6 3	56½	340	72½	435¾
6 6	54¼	326¾	69¾	419½
6 9	52½	314¾	67¼	404½
7 0	50½	303½	65	396¾
7 3	48¾	293	62¾	377½
7 6	47	283¼	60¾	365½
7 9	45½	274	59	354
8 0	44	265¾	57	343¼
8 3	42¾	257½	55½	333¼
8 6	41½	250		

Rule for ⅜-inch Plates.—Divide 4250 by the diameter of the boiler in inches; the quotient is the working pressure, being one-sixth of the strength of the joints.

Rule for ½-inch Plates.—Divide 5666·6 by the diameter of the boiler, and the quotient will be the greatest pressure that the boiler should work to while new; that is, one-sixth of the punched plates.

We now come to the rectangular forms, or flat surfaces, which are not so well calculated to resist pressure. Of these we have many instances: the fire-box of the locomotive boiler, the sides and flues of marine boilers, and the flat ends of cylindrical boilers, and other boilers of weaker construction. The locomotive boiler is generally worked up to a pressure of 120 lbs. on the square inch, and at times, when ascending steep inclines, we have known the steam nearly as high as 200 lbs. on the square inch. In a locomotive boiler subject to such enormous working pressure, it requires the utmost care and attention on the part of the engineer to satisfy himself that the flat surfaces of the fire-box are capable of resisting that pressure, and that every part of the boiler is so nearly balanced in its powers of

resistance, as that when one part is at the point of rupture, every other part is on the point of yielding to the same uniform force. This appears to be an important consideration in mechanical constructions of every kind, as any material applied for the security of one part of a vessel subject to uniform pressure, whilst another part is left weak, is so much material thrown away; and in stationary boilers, or in moving bodies such as locomotive engines and steam vessels, they are absolutely injurious, at least so far as the parts are disproportionate to each other, because when maintained in motion they become an expensive and unwieldy encumbrance. The greater portion of the fire-boxes in locomotive boilers have the rectangular form, and in order to economize heat, and give space for the furnace, it becomes necessary to have an exterior and interior shell. That which contains the furnace is generally made of copper, firmly united by rivets, and the exterior shell, which covers the fire-box, is made of iron, and united by rivets in the same way as the copper fire-box. Now these plates would of themselves, unless supported by rivetted stays, be totally inadequate to sustain the pressure. In fact, with one-tenth of the pressure, the copper fire-box would be forced inwards upon the furnace, and the external shell bulged outwards, and with every change of force these two flat surfaces would move backwards and forwards, like the sides of an inflated bladder, at the point of rupture. To prevent this, and give the large flat surfaces an approximate degree of strength with the other parts of the boiler, wrought-iron or copper stays, 1 inch in diameter, are introduced. They are first screwed into the iron and copper on both sides to prevent leakage, and then firmly rivetted to the exterior and interior plates. These stays are from 6 inches to 4¾ inches asunder, forming a series of squares, and each of these will resist a strain of about 15 tons before it breaks. Let us suppose the greatest pressure contained in the boiler to be 200 lbs. on the square inch, and we have $6 \times 6 \times 200 = 7200$ lbs., or 3¼ tons, the force applied to a square containing 36 square inches. Now as these squares are supported by four stays, each capable of sustaining 15 tons, we have $4 \times 15 =$ 60 tons as the resisting powers of the stays; but the pressure is not divided amongst all the four, but each stay has to sustain that pressure, consequently the ratio of strength to the pressure will be 4½ to 1 nearly, which is a very fair proportion for the resisting power of that part.

We have treated of the sides, but the top of the fire-box and

the ends have also to be protected, and there being no other part but the circular top of the boiler to which to attach stays, it has been found more convenient and equally advantageous to secure these parts with a series of wrought-iron bars, from which the roof of the fire-box is suspended, and which effectually prevents it being forced down upon the fire. It will not be necessary here to go into the calculation of those parts. They are, when rivetted to the dome or roof, of sufficient strength to resist a pressure of 300 to 400 lbs. on the square inch. This is, however, generally speaking, the weakest part of the boiler, with the exception probably of the flat ends above the tubes in the smoke-box, where they are carefully stayed. In the flat ends of cylindrical boilers, and those for marine purposes, the same rule applies as regards construction, and the due proportion of the parts, as in those of the locomotive boiler, must be closely adhered to.

Every description of boiler used in manufactories, and also on board ship, should be constructed to stand at least six times the working pressure, or a pressure of about 500 lbs. on the square inch; and locomotive-engine boilers, which are subjected to a much severer duty, to about 800 lbs. per square inch. Internal flues, such as contain the furnaces in the interior of the boiler, should be kept as nearly as possible to the cylindrical form; and as wrought-iron will yield to a force tending to crush it of about one-half of what would tear it asunder, the flues should in no case exceed one-half of the diameter of the boiler; and, with the same thickness of plates, it may be considered equally safe to the other parts. In fact, we should advise the diameter of the internal flues to be in the ratio of 1 to $2\frac{1}{2}$, instead of 1 to 2 of the diameter of the boiler. Corrugated flues as now made of iron or steel give increased strength.

THE STRENGTH OF ROUND BOILERS WITH DIFFERENT QUALITIES OF PLATES.

When the tensile stress of each boiler-plate is not known per square inch, or the strain that it will bear before breaking, to find the thickness for a certain diameter, multiply the diameter in inches by the steam pressure, dividing the product by one-sixth of the ultimate mean strength of the plate per square inch, and the quotient is the thickness. When the boiler rests on brickwork, add $\frac{1}{16}$ inch more. The tensile strain of the best boiler-plate is about

62,544 lbs., and the worst 34,000 lbs. per square inch. Taking one-sixth of the mean, or 8045 lbs.—(this is presuming the best plates are used; if the plates are of inferior quality, it is obvious the constant is too high proportionally, although it may answer in practice with a parcel of the best plates untested)—we have, for a boiler 6 feet 6 inches in diameter, and with 60 lbs. steam per square inch, the following result (the seams being single-rivetted):—

$$\frac{78 \times 60}{8045} = \cdot 58, \text{ say } \tfrac{9}{16} \text{ inch,}$$

as the thickness, or when set in brickwork say ⅝ of an inch. This is allowed on account of the corrosion that takes place with all boilers resting on a brickwork foundation. The ends should be at least ⅛ inch more than the calculated thickness.

In another form it may be taken thus—

P. Pressure per square inch.
D. Diameter of boiler in inches.
T. Thickness of plates in inches.
C. Constants for varying qualities of plates.

	Double Rivetted.	Single Rivetted.
C=For Yorkshire plates of best quality,.............	7800	6200
C=For Staffordshire plates of best quality,..........	6200	5000
C=For ordinary plates,..	3700	3300

$$T = \frac{P\,D}{2\,C}.$$

It will be seen that this formula gives a thickness of the plates somewhat less than the previous rule, using the best quality, a result not at all to be desired; yet when the quality of the plates is tested by a strip cut off each plate, one-sixth of the strength of the rivetted joints, as per following table, may be safely taken as the constant.

The Strongest Form and Proportion of Rivetted Joints, as deduced from Experiment and Practice.

Thickness of Plates in Parts of an Inch.	Diameters of Rivets in Inches.	Length of Rivets from Head in Inches.	Distance of Rivets from Centre to Centre in Inches.	Quantity of Lap in Single Joints in Inches.
·18 = 3/16	·38 }	·88 }	1·25 } 6	1·25 }
·25 = 1/4	·50 }	1·13 }	1·50 }	1·50 } 6
·31 = 5/16	·63 } 2	1·38 }	1·63 } 5	1·88 }
·37 = 3/8	·75 }	1·63 } 4·5	1·75 }	2·00 5·5
·50 = 1/2	·81 }	2·25 }	2·00 }	2·25 }
·62 = 5/8	·94 } 1·5	2·75 }	2·50 } 4	2·75 } 4·5
·75 = 3/4	1·13 }	3·25 }	3·00 }	3·25 }

For double-rivetted joints, add two-thirds of the depth of the single lap. Where great strength is desirable this form of joint should always be adopted. It will be seen from the following table that the double-rivetted joints retain their resisting power, while the single-rivetted joints lose about one-fifth of the actual strength ot the plates.

The figures 2, 1·5, 4·5, 6, 5, &c., given in the preceding table are multipliers. These multipliers are considered as proportionals of the plates; thus, supposing we take ⅜ of an inch as the thickness of plates, we have simply to multiply the thickness by the number to find the proportionate quantities to form the strongest joint:—

	Inches.	
$\cdot375 \times 2$	$= \cdot750$	diameter of rivet.
$\cdot375 \times 4\cdot5$	$= 1\cdot687$	length of rivet.
$\cdot375 \times 5$	$= 1\cdot875$	distance between rivets.
$\cdot375 \times 5\cdot5$	$= 2\cdot062$	quantity of lap, single rivetted.
$\cdot375 \times 9\cdot1$	$= 3\cdot412$	quantity of lap, double rivetted.

It will be seen that the dimensions thus found nearly agree with the dimensions in the preceding table, which are practically correct.

Boilers are now being made of steel: as made by the Siemens or Bessemer process, the tensile strength is about 29 tons per square inch, and the elastic strength appears to lie within 11 to 16 tons per square inch. Test pieces, 10 inches long, give an elongation of 28 per cent., with a contraction of area of about 49 per cent. Punching the rivet holes weakens the metal by about 30 per cent.; the strength can, however, be restored by annealing. Drilling the holes does not seem to affect the strength. By the use of steel the weight of boilers has been reduced about 10 per cent. For further reference to manufacture and strength of steel see section on Shipbuilding, p. 960.

Mean Strength of Plates in the direction of and across the Fibre (*Fairbairn*).

	Breaking Weight in the direction of the Fibre, in tons per square inch.	Breaking Weight across the Fibre, in tons per square inch.
Yorkshire Plates.........	25·720	27·490
Do. do.	22·760	26·037
Derbyshire do.	21·680	18·650
Shropshire do.	22·826	22·000
Staffordshire do.	19·563	21·010
Mean................	22·509	23·037

Tensile Strength of Single and Double Rivetted Plates.

Cohesive Strength of Plates. Breaking Stress in Lbs. per Square Inch.	Strength of Single Rivetted Joints, of equal Section to the Plates, taken through the Line of Rivets.	Strength of Double Rivetted Joints, of equal Section to the Plates, taken through the Line of Rivets.
57,724	45,743	52,352
61,579	36,606	48,821
58,322	43,141	58,286
50,983	43,515	54,594
51,130	40,249	53,879
49,281	44,715	53,869
43,805	37,161	...
47,062	...	...
Mean, 52,485	41,590	53,633

Area of boiler stays $= \frac{A \times p}{t}$, where A=area of surface of plate held by one stay, and p and t being the pressure and tenacity respectively.

The following value of plates may be fairly assumed with those of joints:—

Plates.............................. 100
Double Rivetting.................. 70
Single Rivetting.................. 56

In a series of experiments by Napier the tensile strength of iron plates averaged from 56,735 to 41,743 lbs. per square inch.

Weight of a Square Foot of Wrought-iron Plate from $\frac{1}{32}$ to 1 inch in Thickness.

Thickness in inches.	Weight in lbs.	Thickness.	Weight.
$\frac{1}{32}$	1·25	$\frac{1}{2}+\frac{1}{32}$	21·25
$\frac{1}{16}$	2·5	$\frac{9}{16}$	22·5
$\frac{1}{16}+\frac{1}{32}$	3·75	$\frac{9}{16}+\frac{1}{32}$	23·75
$\frac{1}{8}$	5·	$\frac{5}{8}$	25·
$\frac{1}{8}+\frac{1}{32}$	6·25	$\frac{5}{8}+\frac{1}{32}$	26·25
$\frac{3}{16}$	7·5	$\frac{11}{16}$	27·5
$\frac{3}{16}+\frac{1}{32}$	8·75	$\frac{11}{16}+\frac{1}{32}$	28·75
$\frac{1}{4}$	10·	$\frac{3}{4}$	30·
$\frac{1}{4}+\frac{1}{32}$	11·25	$\frac{3}{4}+\frac{1}{32}$	31·25
$\frac{5}{16}$	12·5	$\frac{13}{16}$	32·5
$\frac{5}{16}+\frac{1}{32}$	13·75	$\frac{13}{16}+\frac{1}{32}$	33·75
$\frac{3}{8}$	15·	$\frac{7}{8}$	35·
$\frac{3}{8}+\frac{1}{32}$	16·25	$\frac{7}{8}+\frac{1}{32}$	36·25
$\frac{7}{16}$	17·5	$\frac{15}{16}$	37·5
$\frac{7}{16}+\frac{1}{32}$	18·75	$\frac{15}{16}+\frac{1}{32}$	38·75
$\frac{1}{2}$	20·	1	40·

Weight of Angle Iron, in Lbs. per Lineal Foot.

Breadth in inches............... 1¼, 1½, 1¾, 2, 2¼ 2½, 2¾, 3, 3¼, 3½.
Weight per foot in lbs........ 1·8, 2·7, 3·3, 3·9, 5, 6·5, 8·3, 10·4, 11·7, 14.

Weight of a Lineal Foot of Square and Round Bar Iron, in Lbs.

Size.	Square Bar.	Round Bar.	Size.	Square Bar.	Round Bar.	Size.	Square Bar.	Round Bar.
1/4	·209	·164	1¼	5·25	4·09	3	30·07	23·60
5/16	·326	·256	1⅜	6·35	4·96	3¼	35·28	27·70
3/8	·470	·369	1½	7·51	5·90	3½	40·91	32·13
7/16	·640	·502	1⅝	8·82	6·92	3¾	46·97	36·89
1/2	·835	·656	1¾	10·29	8·03	4	53·44	41·97
9/16	1·057	·831	1⅞	11·74	9·22	4¼	60·32	47·38
5/8	1·305	1·025	2	13·36	10·49	4½	67·63	53·12
11/16	1·579	1·241	2⅛	15·08	11·84	4¾	75·35	59·18
3/4	1·879	1·476	2¼	16·91	13·27	5	83·51	65·58
13/16	2·205	1·732	2⅜	18·84	14·79	5¼	92·46	72·30
7/8	2·556	2·011	2½	20·87	16·39	5½	101·63	79·35
15/16	2·936	2·306	2⅝	23·11	18·07	5¾	114·43	86·73
1	3·34	2·62	2¾	25·26	19·84	6	120·24	94·43
1⅛	4·22	3·32	2⅞	27·61	21·68			

Surface of Tubes per Lineal Foot, in Square Feet.

Diameter inch	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½
Surface......	·1636	·1963	·2291	·2618	·2945	·3270	·3599	·3927
Diameter inch	1⅝	1¾	1⅞	2	2¼	2½	2¾	3
Surface............	·4253	·4580	·4906	·5233	·5890	·6544	·7199	·7854

Weight per Foot in Lbs. and Decimal Parts of Iron, Brass, and Copper Tubes.

Inches External Diameter.	Birmingham Wire Gauge.	Iron.	Brass.	Copper.	Inches External Diameter.	Birmingham Wire Gauge.	Iron.	Brass.	Copper.
1½	13	1·402	1·529	1·627	3¾	9	5·640	6·148	9·500
1⅝	13	1·528	1·665	1·772	4	8	6·652	7·250	7·716
1¾	13	1·653	1·801	1·917	4¼	8	7·087	7·724	8·220
1⅞	12	2·024	2·206	2·347	4½	8	7·497	8·171	8·696
2	12	2·168	2·363	2·514	4¾	8	7·953	8·668	9·225
2⅛	12	2·311	2·513	2·680	5	7	9·120	9·940	10·579
2¼	11	2·687	2·928	3·116	5¼	7	9·596	10·459	11·131
2½	11	3·002	3·272	3·482	5½	7	10·089	10·997	11·603
2¾	10	3·685	4·016	4·274	5¾	7	10·539	11·487	12·225
3	10	4·038	4·401	4·684	6	6	12·371	13·484	14·350
3¼	9	4·826	5·260	5·598	7	6	14·168	15·444	16·435
3½	9	5·215	5·684	6·049					

PROPORTIONS FOR PLAIN LAND BOILERS.

Shell.—Having pointed out the principles to be observed in construction, we will proceed to give the proportions generally adopted in steam boilers. For each nominal horse-power make an allowance of 1 cubic yard, or 27 cubic feet capacity; this is simply the

cubical contents of the shell, with or without inside flues. Supposing, for the sake of illustration, a Cornish boiler of 40 nominal horse-power was required, multiply the horse-power by 27 cubic feet, and the result will be the cubical contents, thus—

$$40 \times 27 = 1080 \text{ cubic feet.}$$

Length and Diameter.—The length of the boiler should be about three and one-half times the diameter for moderate power, or up to about 20 horse-power inclusive; above that size five times the diameter can be adopted—a little more or less can do no harm. To find the diameter, multiply 1080, the cubical contents required, by the *constant* 1·28, dividing the result by the proportion of the diameter to the length, say five times, and the cube root of the quotient will be the diameter, which, multiplied by 5, gives the length of the boiler nearly.

$$\frac{1080 \times 1{\cdot}28}{5} = \sqrt[3]{276{\cdot}48} = \text{say } 6{\cdot}5 \times 5 = 32{\cdot}5.$$

The length of the boiler, in round numbers, is 32·5 feet, and 6·5 feet in diameter. To check the calculation, the area of 6·5 feet in diameter is 33·18 square feet × 32·5 = 1078·35 cubic feet, within a trifle of what is required.

Heating Surface, Fire-grate, and Flue Area.—The heating surface should not be less than 1 square yard, or 9 square feet, per nominal horse-power; but in ordinary boilers it will be found that more than this can be conveniently got. The area of the fire-grate, when the furnace is underneath the boiler, should be 1 square foot, and when the furnace is in a flue, forming part of the boiler, ·75 of a square foot will be sufficient, per nominal horse-power. The length of the fire-grate should never exceed 7 feet. When the furnaces are placed inside of the boiler, for small diameters, the inside flues should be 2 feet 6 inches in diameter, and certainly not less than 2 feet 3 inches. When smaller than this, the fires do not burn well, and they are troublesome to fire; for large diameters of boilers, the furnace flues can be 3 feet 3 inches in diameter. The area of the furnace flues should be about 28 square inches per nominal horse-power, a little more doing no harm; thus for 40 horse-power, we have for two furnaces—

$$40 \times 28 = 1120 \div 2 = 560 \text{ square inches,}$$

equal say 2 feet 3 inches diameter for each flue in the boiler, and 4 feet 6 inches as the sum of the width for both; thus, for the

length of the grate, making an allowance of ·75 of a square foot per nominal horse-power, we have—

$$\frac{40 \times \cdot 75}{4 \cdot 5} = 6 \cdot 6 \text{ feet in length.}$$

The area over the bridge is generally about 18 square inches per nominal horse-power.

Water and Steam Room.—For boilers with hemispherical ends, the water should fill the boiler two-thirds of its diameter, thus leaving one-third as steam-room. For Cornish arrangement with two furnaces (otherwise known as the Butterly boiler) the water generally fills the boiler three-fourths of its diameter, the remainder being the steam-room. One foot height of water over the furnaces is allowed; when one furnace is adopted the steam-room in the boiler can be increased, and it is always advisable to have steam domes fitted to the top.

RELATIVE VALUE OF HEATING SURFACE.

Horizontal surface above the flame,................................	=1·0
Vertical ,, ,, ...	=0·5
Horizontal surface below the flame,................................	0·0
Tubes and flues................................	= 1¼ of their diameter.

BOILER FOUNDATIONS.

With the foregoing proportions we may now commence to lay out the boiler foundations. The boilers are generally ordered in duplicate, so that no stoppage may occur in the event of one of them requiring repairs; indeed, when deposits rapidly form from impurities in the water, frequent inspection is necessary, periodical scaling and cleaning out being required. After the ground is excavated, a bed of concrete is laid all over, on which is built the superstructure for carrying and bedding the boiler thereon. The Cornish or London boiler, with inside furnaces, rests on a mid wall, having cast-iron supports imbedded in the middle wall, and should be of sufficient height to leave about 3 feet 4 inches from the stoking-floor to the dead plates on the furnace front. The boiler is surrounded with what is technically termed a wheel-flue, that is to say, the flame and the heated gases pass through the internal furnaces and the back flues contained in the boiler, then wheel round at the end, and return to the front—along one side, and pass along the other side nearest the chimney, an opening being left in the mid wall at the bottom

for the flame and the gases to cross from one side of the boiler to the other side nearest the chimney, and they escape into a flue

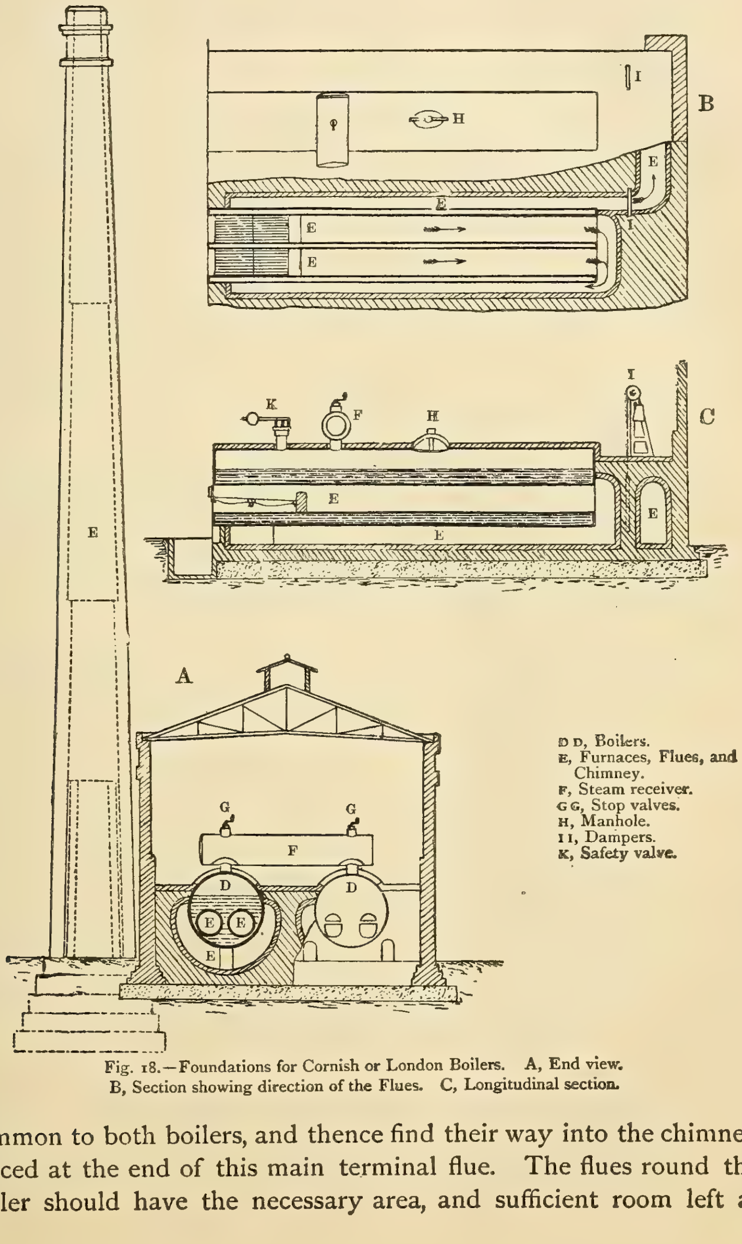


Fig. 18.—Foundations for Cornish or London Boilers. A, End view. B, Section showing direction of the Flues. C, Longitudinal section.

common to both boilers, and thence find their way into the chimney placed at the end of this main terminal flue. The flues round the boiler should have the necessary area, and sufficient room left at

the bottom for the convenience of executing repairs and cleaning out the flues. To resist the action of the flame the flues are lined with fire-brick, and at the front of the building openings are left, which are fitted with cast-iron doors for the convenience of periodical inspection of the boiler.

Damper-plates are fitted to each boiler. They are simply cast-iron plates, sliding in suitable frames of cast-iron imbedded in the building. The damper-plate has a "snug" cast on for attaching a chain provided with a back balance weight, the chain passing over a pulley, carried up by means of a cast-iron pedestal, securely fastened down to a large stone imbedded in the top courses of the brick-work. Sometimes the revolving pulley can be carried up from a plate and pin secured to the wall of the boiler-house. To protect the top of the boiler from radiation, it is arched over with fire-bricks, the space between the boiler and the brick arch being filled in with ashes, and sometimes sand is used.

The walls of the boiler-house are covered over with a suitable wrought-iron roof, having a ventilator at the top for carrying away any waste steam that may blow off. The arrangement of the flues just described will suit all boilers having internal furnaces; but when the boiler is constructed with one internal small flue, it is preferable to form the furnace underneath.

Now for cylindrical arrangements, having hemispherical ends, this class of steam-generators is usually longer in proportion to the diameter than the Cornish type; in some instances six and three-quarter times the diameter has been adopted. The buildings are very different from the foregoing example. The same height from the stoking-floor to the dead-plate is allowed, namely, 3 feet 4 inches. This plate is made long, so that the coal may cake before being pushed amongst the incandescent fuel, this effecting a considerable economy when properly attended to. A height of about 2 feet 4 inches is allowed in large boilers, from the top of the fire-bars to the under-side of the boiler; and the flues are arranged on the wheel principle, as in the Cornish type, with this difference, that the flame passes underneath the boiler, and then ascends at the back, all round, and thence up the chimney. There is a combustion chamber formed at the back of the bridge, at the end of the fire-bars furthest from the front, the flame as it were hanging at the hollow left in the bottom flue, thus making the bottom surface of the boiler very effective as heating surface. This recess likewise serves the purpose of collecting

both the ashes and the soot that may be drawn over by the draught, and which are raked out through a hole, fitted with a movable door,

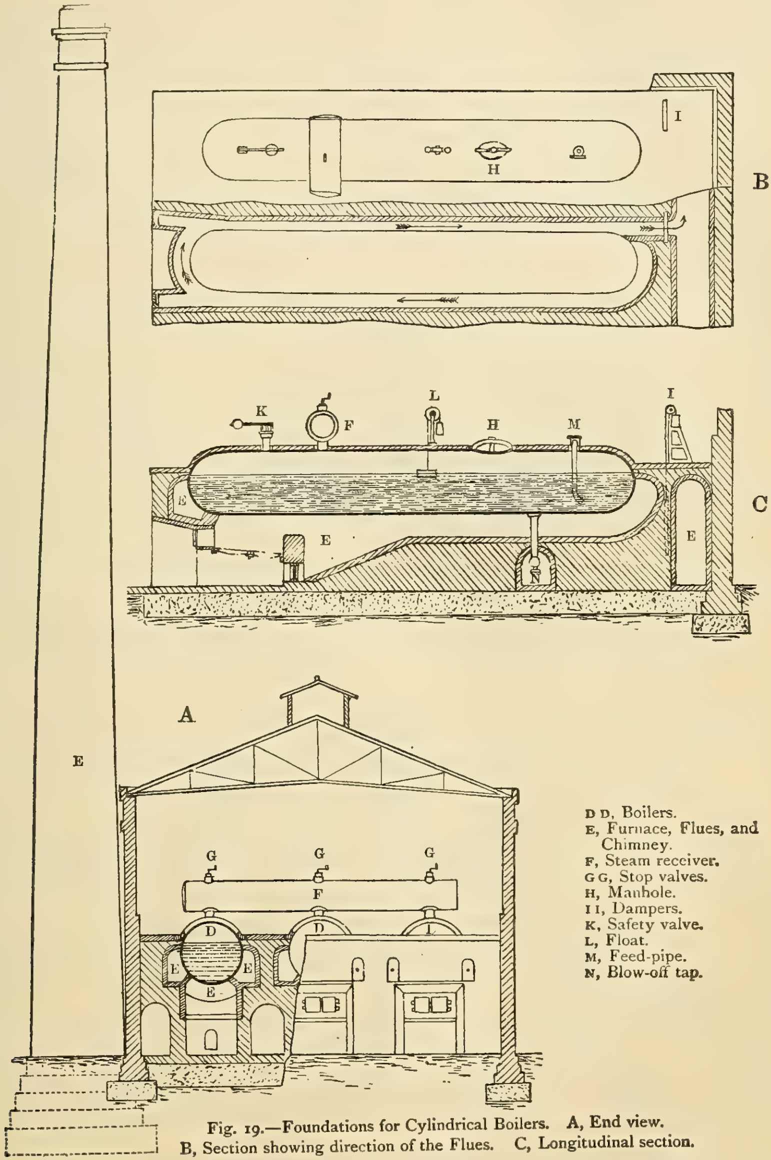


Fig. 19.—Foundations for Cylindrical Boilers. A, End view. B, Section showing direction of the Flues. C, Longitudinal section.

placed at the bottom of the bridge. The boiler is usually set with a dip towards the back of ⅛ inch to the foot, so that the sludge

may collect at the part farthest from the fire. A plug-valve is fitted to the underside of the boiler, to which is attached a pipe leading into a drain left in the building; by this means the water flows away when the boilers are blown off. The buildings are generally hollowed out to lighten the structure, and the boiler is fitted with brackets, bolted to the top, so as partly to take the weight; but the main support is at the sides of the furnace, the furnace walls being carried up from the bed; but at times when the sides of the furnace are undergoing repair, the top brackets take the weight. All the flues must have sufficient area, as likewise doors must be left in the brickwork for cleaning them out; the height from the top of the bridge to the under side of the boiler is generally about 18 inches. The fittings are just the same as for the Cornish boiler, having a wrought-iron steam-chest connecting all the boilers, provided with a stop-valve to each boiler, with the addition of a stone float and back-balance for indicating the height of the water inside of the boiler. No float is required for the Cornish class, as the ordinary water-gauge is fitted to the front end; hemispherical-ended boilers, however, can have a gauge-glass in front, with suitable pipe connections passing through the brickwork. The safety-valve is placed on the top, at the fire-end, then the stop-valves, next the float of stone with weight, then the manhole, and the feed-pipes at the back of the boiler, all placed on the centre line.

We will now notice the arrangements for one small internal flue. The furnace is placed underneath the boiler, the flame acting on the bottom, and then through the small tube, which carries it to the front, the flame splitting as it were at the front end, passing down each side, and meeting at the back in one central flue, in the same line as the centre of the boiler; this is required so that the draught may be equalized in the side flues, as the heated gases have always a tendency to take the shortest passage into the chimney. Some boilers of the cylindrical type, with hemispherical ends, are hung from the top with brackets, having no support underneath, the flame acting on the bottom and the sides, and then passing directly into the chimney; this is not so good an arrangement as the return flues, as the flame and the heated gases have no time to act on the surfaces, unless boilers of inconvenient length are adopted. The furnace bars should be made in suitable lengths, having a thickness of ⅞ inch at the top, and ½ inch at the bottom, with

projections at the ends, and the middle of the top, the openings between the bars varying from ⅜ to ½ inch, to suit soft

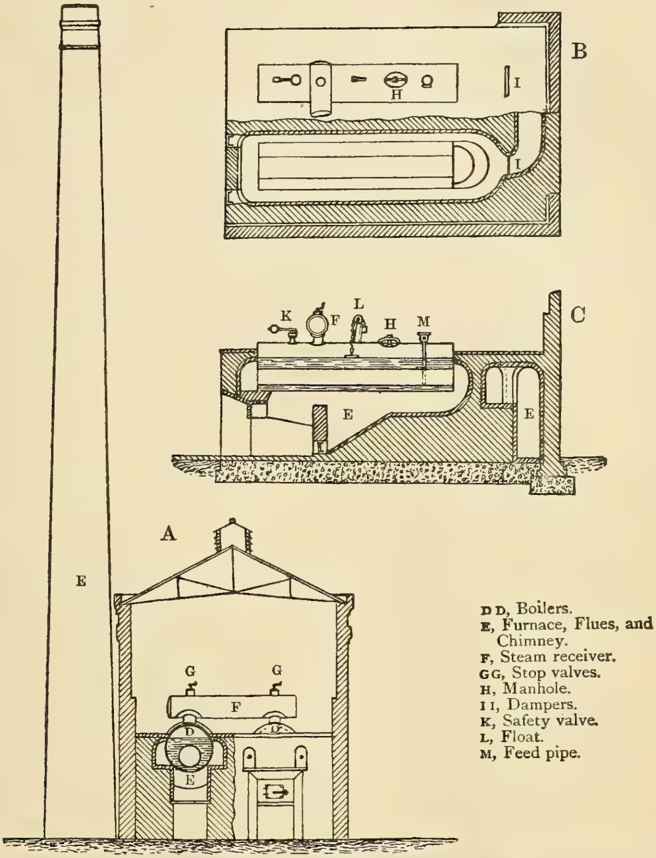


Fig. 20.—Foundations for Boilers with small Internal Flue. A, End view. B, Section showing direction of Flue. C, Longitudinal section.

and hard coal, the depth of the bars at the middle being from 3½ to 4 inches.

AREA AND DIMENSIONS OF CHIMNEY.

To determine the area of tne top of the chimney for a given consumption of coal per hour, the average for Cornish boilers being 10 lbs. per nominal horse-power, multiply the number of lbs. consumed per hour by 12, and divide the product by the square root of the height of the chimney in feet (the usual height for factory

chimneys being 80 feet), and the quotient is the area at the top of the chimney, thus for 40 nominal horse-power—

$$\frac{40 \times 10 \times 12}{\sqrt{80}} = 539, \text{ say 26 inches diameter,}$$

or 23 inches square at the top. It is always preferable to make an allowance over and above this for the convenience of leading other flues into it. For a chimney 80 feet in height the brickwork should be divided into three courses: for 30 feet height from the bottom two bricks in thickness, the next course one and a half brick in thickness, and the remainder one brick thick. For each 25 feet added in height the brickwork at the bottom should be increased one-half brick in thickness. The batter or the slope of the side is usually 0·3 of an inch to the foot. Thus, with 26 inches inside diameter at the top, the bottom of the chimney would be 92 inches external diameter, while that of the top would be 44 inches. Should the internal diameter at the top require to be 54 inches and upwards, the top course should be one and a half brick in thickness, and the bottom courses in proportion. The inside at the bottom is lined with fire-bricks, leaving a space of one inch between the inner lining and the main building, and is carried up to a height of 15 feet from the bottom. For a chimney 80 feet in height the foundation should be at least 5 feet in depth, laid on a bed of concrete 2 feet in thickness, but this will depend on the soil; on sand or gravel this bed will be quite sufficient, but of course some soils require the foundation to be carried down to a firm bed. In marsh land, and even for the Colonies, wrought-iron chimneys may be used with advantage, but brick chimneys are to be preferred. The best temperature for an efficient chimney draught is about 600° Fahr.

SMOKE PREVENTION.

Although the distance between the fire-bars varies from ⅜ to ½ inch, allowing a good volume of air underneath the grate, so essential for perfect combustion, other means must be taken to consume the gaseous constituents thrown off from coal when in the semi-incandescent state; the simplest and most effectual way of doing this is by admitting a current of air through a series of small holes drilled through the furnace door, thus supplying the common oxygen contained in the atmosphere, and of which we have an unlimited command. Many schemes have been brought forward from time to time to consume the gases evolved before a dense mass of smoke

is formed in the flues, for if the gases are not consumed before reaching the flues, it is impossible to burn the smoke with the ordinary arrangements; but those who are under the impression that smoke, or at least what we term smoke, cannot be burned when once formed, labour under a sad mistake, for the densest volume passing through a regenerative furnace is effectually consumed.

We will take the Butterly boiler, having two internal flues or furnaces meeting in one combustion chamber at the back of the bridge: fire both of these furnaces at one and the same time, and dense volumes of smoke will be seen issuing from the top of the chimney; the smoke is formed in the furnace, and passes over the bridge. Now this arrangement, with careful firing, in a great measure prevents smoke issuing from the chimney. One fire should be bright while the other one is dull, or in the act of firing, and what is the consequence? the combustion chamber is in a perfect glow, from the bright fire; and the smoke evolved by the dull one is effectually consumed by the other. This simple fact is half of the battle; careful firing is the best and most economical means for the prevention of smoke; so by alternately firing little or no smoke is seen issuing from the top of the chimney. Such practice every good fireman is perfectly conversant with.

As hydrogen is the main element in the gases evolved, and by the admixture of the oxygen of the atmosphere flame is produced; and as neither hydrogen nor oxygen can burn of itself, it remains for us to supply a current of air, so as to obtain the most economical result from the fuel. With the common blow-pipe an intense heat is obtained by simply blowing a current of air through a flame of gas, or rushes, as used by the gasfitter. And in the smelting furnace air is forcibly blown through a coil of pipes, surrounded and inclosed in a furnace, the air is thus intensely heated, and, indeed, will melt a bar of lead before it is admitted into the smelting furnace; this is termed the "*hot blast*," and is familiar to all metallurgists. Were it not for the complication entailed, this method would be by far the best plan that could be adopted for steam boilers, but such an intense heat is not at all desirable, for should the water in the boiler fall below the working level, the plates would get intensely hot, and an explosion would be the inevitable result; so a moderate measure of heated air is all that is required.

A very simple plan for introducing heated air is by arranging small pipes, fixed to the front plate of the boiler, as in the double

furnace Lancashire class, the pipes passing through the water space to the combustion chamber plate, through which they are securely rivetted, or clenched over. Thus a current of hot air passes through the tubes, mixing with the flame and gases in the combustion chamber, so that when the fires are properly attended to, as with all arrangements introduced for the prevention of this nuisance they must be, little or no smoke will appear at the top of the chimney. The introduction of heated air into the combustion chamber after the smoke or gases have passed the bridge, seems mainly to keep up the temperature of the flues, by the admixture of the oxygen of the atmosphere with the flame in the combustion chamber; this plan, where it can be conveniently applied, should always be adopted. As before stated, vertical boilers are so fitted with a series of small air-tubes all round the fire-box, inclining downwards, thus the air freely mixes with the live coal. In former years some persons scouted the idea of consuming the smoke after passing the bridge; the fact of our now being able to do so speaks for itself. Some may term it gas before it has passed the bridge; but what we plainly see in the furnace we denominate smoke.

For single furnaces a very different arrangement is adopted, the smoke being consumed in the furnace: the fire-door is perforated with a number of small holes ⅜ inch in diameter, drilled closely together. It seems impossible to give the exact number of holes to suit all furnaces, as the same furnace, with different kinds of coal, requires more or less openings, as the case may be, and even the same furnace often requires more or less air with the same kind of coal; this may be owing to the temperature of the atmosphere, or which way the wind is blowing; if blowing in such a direction as to fan the fire, as in the forward boilers for marine purposes, less air will do at the furnace door. Thus it is imperative to have a great number of holes, say 5 to 6 square inches for every foot of fire-grate surface; they should be covered with a regulator, or movable disc-plate, with corresponding holes for regulating the supply; some adopt slits instead of round holes, but the latter, or jet system, is by far the best, as it distributes the air equally amongst the gases in the furnace. This plan necessitates regulation by the damper. Should no steam be required, or the engine not working, or even when the fireman is trimming the fire, the damper can be shut, checking the draught for a time; the smoke remains in the furnace, or is slowly consumed there, thus preventing it issuing at the chimney top.

Another plan for consuming the smoke is attained by blowing superheated steam through a number of minute apertures placed at the front of the furnace; with high-pressure steam in the boilers; this plan works well, so long as the apparatus remains in good order. The steam requires to be dry before it is sprayed into the furnace in minute jets above the grate. The steam from the boiler is made to flow through a coil of pipes placed in the fire-brick bridge, and then passes through a pipe laid across the furnace front, fitted with nozzles having holes $\frac{1}{16}$ inch in diameter; the pipe is fitted with a plug-valve to regulate the supply to the nozzles, the furnace door being provided with a number of air holes, the superheated steam is turned on, causing a powerful current of air to pass through the fire door, and before mixing with the gases in the furnace is distributed with the steam jets into minute atoms, and we may say the mere forcing of the atoms driving the oxygen through and between the live coal, produces complete combustion, with great economy in fuel. This is much better than any plan we know of, from the fact that fuel will burn with this arrangement that would be entirely worthless in ordinary furnaces. By the use of the jets of superheated steam all the waste cinders from the smithy can be utilized, and dross or small coals effectually burned, without the smoke nuisance; but we unhesitatingly give as our opinion, that unless the attendant sees that the furnace is kept in proper trim, firing with the least quantity of coal, oft times replenished, that all the refinements for the prevention of smoke will not attain the desired object, for careful firing is the main secret to arrive at.

SYSTEMS OF TUBING.

The triangular and square systems of tubing have certain advantages as well as disadvantages. With the former, almost used exclusively fcr locomotive boilers, a greater number of tubes can be got into less space, the water being honey-combed as it were with a large amount of heating surface. The tubes for locomotive boilers are generally made of composition metal; this is absolutely required where deposits form from impurities in the water. When iron or steel tubes are used, the small water spaces, in some instances only half an inch, soon get choked up, and the steam does not rise freely; and as the arrangement will not allow of much scraping and clean-

ing, were deposits forming to any great extent, it would soon prove fatal to the boiler. To partially remedy this evil the boiler should

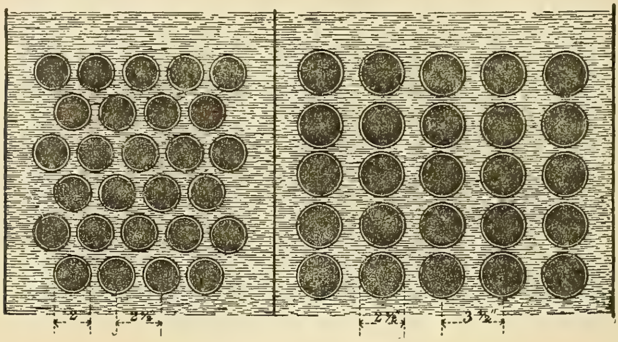


Fig. 21.—Systems of Tubing.

be emptied every day, while for other boilers the water must be blown off frequently. With the triangular system of tubing the steam generated from the bottom row of tubes must take many a zigzag course before reaching the top, or the steam space. To obviate the difficulties attending the triangular system the square plan is adopted, more especially for marine boilers, so that when iron or steel tubes are used there is some possibility of scraping and cleaning them occasionally; and even where composition tubes are adopted the square system finds favour, as the globules of steam generated from the tubes pass up in parallel rows between the tubes, instead of following the zigzag course as in the triangular system.

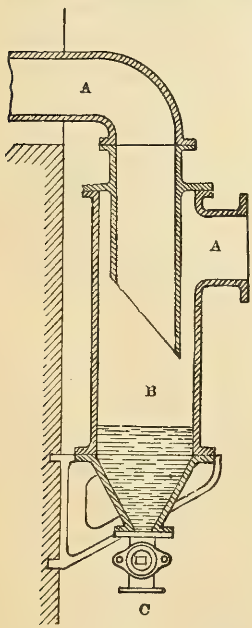


Fig. 22.—Separator. A, Steam-pipe. B, Receiver. C, Tap.

DRY STEAM.

In order to provide as dry steam as possible, without using a superheater, there should be steam-chests of ample capacity fitted to all land boilers, in fact we may say to every class of boiler where they can be conveniently applied; but as the steam still contains watery particles, a separator may be fitted to the steam-pipe. The action of this contrivance is very simple, and consists in abruptly

changing the flow or current of the steam. To a vertical chamber a right-angled pipe is suspended, passing down into the chamber a little below the exit pipe; the steam flowing through the pipe from the boiler impinges against the elbow, causing the moisture contained in the steam to trickle down the pipe, thus the water is collected at the bottom of the receiver, and is drawn off at pleasure with a tap; this plan is very simple, and it can be made self-acting by means of a float and valve. We consider these separators for drying the steam, or rather separating the moisture contained in the steam, should be fitted to all steam-pipes.

Taking Low-pressure Steam from a High-pressure Boiler.—Sometimes it is desirable to reduce the pressure of the steam, so as to work a low-pressure engine from a high-pressure boiler. There are a variety of plans for doing so; we have an equilibrium valve, actuated by the pressure of the steam acting on a piston open to the atmosphere, and regulated by a lever and spring-balance, similar to the safety-valve on the locomotive engine boiler. The valve is formed of five rings cast together, with four vertical arms, or ribs, having a boss for securing the valve-spindle; this annular tube moves in a corresponding seat, cast together, with vertical pieces between the openings; there is an annular passage all round the seat, with a branch pipe communicating with the steam-boiler. On the lower part of the valve-chest a branch pipe is cast in communication with the cylinder of the valve-casing of the engine, and on the top of the chest a short cylinder and piston are arranged, the piston being connected to the valve by a screwed rod and nuts. The combined circumferential openings in the valve are equal in area to that of the pipe from the boiler, and the pipe for the engine must be of sufficient area according to the usual rules for steam-pipes. By this contrivance the steam can be regulated to the greatest nicety. The action is as follows:—After being properly set with the nuts on the valve-spindle, and the thumb-screw on the balance at the end of the lever, should there be an accumulation of steam in the chest, after passing the valve, the steam acts on the piston in connection with the valve, and by its pressure lifts it partially, shutting the apertures until the

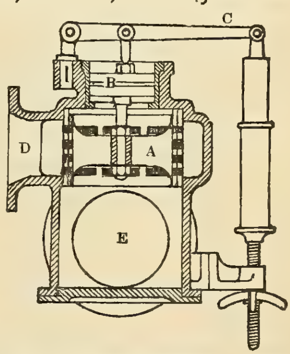


Fig. 23. — Steam-reducing Valve. A, Valve. B, Piston. C, Lever and spring-balance. D, Branch from boiler. E, Branch to cylinder.

balance is restored, thus keeping up constant low pressure, regulated at pleasure by the thumb-screw pressing down or releasing the piston and the valve. One of these valves can be fitted to the main steam-pipe, or a separate one for each cylinder when required.

THE DETERIORATION OF LAND BOILERS.

After a time the plates of all boilers deteriorate, the iron becomes brittle, and although the plates have a sound-looking exterior, without the slightest symptoms of corrosion, yet such a boiler should not be worked beyond a certain number of years, and certainly not at so high pressure as it was originally designed for; in fact, the steam pressure should decrease year by year, so as to work it with any degree of safety. It must be understood, however, that unless a new boiler is properly managed, it is quite as unsafe as a much older one well managed. To determine the number of years a boiler ought to last, with fair treatment, we must have recourse to experiment. When it is thought a boiler has done enough duty *test it to destruction.* Such experiments are very easily carried out, and it is the interest of steam users to do so, that correct data may be arrived at by a careful experimentalist.

We place before our readers the results of a series of experiments, testing two boilers to destruction, instituted by Mr. Peter Carmichael,[1] and which forms a useful contribution on the subject of steam-boilers. The boilers were cylindrical, with double flues, and were used at the Dens Works, Dundee, for *nineteen years.* They were precisely alike, and of the following dimensions:—Length, 25 feet; diameter, 7 feet; diameter of furnaces and end flues, 2 feet 9 inches; diameter of back end of flues, 2 feet 6 inches. The shell was made of ⅜ inch "Glasgow best iron;" the flues of Glasgow best scrap iron, ⅜ inch thick, the end plates being $\frac{7}{16}$ inch in thickness. The boilers were kept in work until the beginning of November, 1869, when it was resolved to take one out, and test it to destruction by water pressure. In the case of the above boilers the pressure has never been so great as 60 lbs., and as reported they were not wasted, having always been kept in good repair, and have stood the periodical water test of 60 lbs.; therefore we may presume they could have been worked for a year or two longer. The fact of the iron getting hard and brittle after being in use for a length of time had

[1] See *Trans. Inst. Engineers and Shipbuilders in Scotland*, vol. xiii.

been often pointed out, and in consequence the pressure ought to be lowered, or new boilers introduced, after they have been working for sixteen or seventeen years. Before testing, all the brick flues were taken down, so that easy access could be got to all parts of the boiler, but it was left sitting on its natural seat. The boilers were filled with water of about 120° temperature, and a force-pump was then attached. To check off the pressure no fewer than five pressure-gauges were used, four of which nearly indicated the same pressure and tallied with the safety valves. At 80 lbs. pressure per square inch an examination was made, and all appeared to be right; but as soon as the pump was started again the joint of the safety valve was blown out, and this stopped proceedings for a time. After this joint had been made good the pressure was again brought up, and at 85 lbs. the joint of the feed-pump pipe, at the front end of the boiler, began to leak, owing to the bulging out of the end. At 100 lbs. a number of the longitudinal seams of the shell began to exude water badly. The pressure was then removed, and the ends gauged above and below the flues, and on the pressure being again put on the following was the result:—Front end below flues bulged out in centre $\frac{3}{16}$ inch at 35 lbs. pressure; $\frac{3}{8}$ inch at 100 lbs. pressure; front end above flues bulged out in centre $\frac{4}{32}$ inch at 35 lbs. pressure, $\frac{7}{32}$ inch at 100 lbs. pressure; back end below flues bulged out at cêntre $\frac{4}{32}$ inch at 35 lbs. pressure, $\frac{5}{32}$ inch at 100 lbs. pressure. The pressure was then brought up to 105 lbs., when the ring seam at the back of the taper of the left-hand flue began to crack, and the pump became unable to keep up the pressure, owing to the great leakage. This joint or seam when gauged, before testing, measured 2 feet 3¾ inches horizontally, by 2 feet 5 inches vertically; and it gave way by crushing inwards on the flat or horizontal side, and remained flattened after the pressure was taken off. This boiler was then removed, and sent to the foundry for breaking up.

Mr. Carmichael proceeded to clear away the brick flues from the sister boiler. On the 15th December, 1869, it was tested in the same way, having been in use for rather more than nineteen years. The flues were gauged, and were found, with one exception, similar to the other boiler. The exceptional one being 1½ inch oval, it was attempted to support this flat part by fixing a batten in the line of the shortest axis of the ellipse, but this was not found to be of any use, as the plate bulged, oozed out below at one end of

the batten and above at the other end, and loosened it when the strain came on. The pressure was noted as before; at 60 lbs. pressure the feed-pipe began to leak, the end bulging out $\frac{1}{16}$ inch. At 80 lbs. the feed valve joint leaked very much, and the longitudinal seams of the shell began to exude water; at 90 lbs. the south or right-hand flue began to crack, as if giving way; at 95 lbs. one of the joints of the shell, and the first rings on the crown of the boiler, commenced to spout water, and the pressure could not be kept up, the leakage being equal to the supply of the force-pump. The joints of the feed-valve were then tightened, and also some parts of the shell caulked, the right-hand flue being found to be very much flattened. The pressure was again put on, but it could not be got higher than 80 lbs., as the flues had given way so much as to allow the water to escape by the fracture as fast as it was pumped in; so that the highest pressure attained was 95 lbs., and this pressure had so injured the joints and flattened the flues as to render further experiment impossible. According to Fairbairn's rules the bursting pressure of these boilers was about 300 lbs. on the square inch, yet they failed with one-third of this pressure. When the boilers were broken up the plates were very brittle; indeed, so much so that it was a difficult matter to get strips for testing. The rivets had likewise deteriorated, and the heads flew off when the plates were struck with a hammer. The test strips gave the following results:—Shell in the direction of the fibre, 19·7 tons; across the fibre, 19·2 tons; while Glasgow best plates is 24·04 tons in the direction of the fibre, and 21·8 tons across the fibre. Furnace plates, direction of fibre, 17·1 tons; ditto across, 15·3 tons. It will thus be seen that the mean of the shell plates is 19·45 tons, and that of the furnace 16·2 tons. Thus the furnace plates had deteriorated or weakened from 22·7 tons to 16·2 tons, while the shell had weakened from 22·92 tons to 19·45 tons. Now this is after the boilers had done duty for nineteen years; so we are of opinion that sixteen years is quite long enough for boilers similarly constructed to be in use: and we trust other firms will follow Mr. Carmichael, so that this all-important question of the deterioration of boiler plates that have not shown the slightest symptom of corrosion, as in these boilers, may be finally determined, with different qualities of plates.

In recording the testing of another old steam boiler, Mr. Carmichael states,[1] "The result of the test so nearly coincides with that

[1] See *Trans. Inst. of Engineers and Shipbuilders in Scotland*, vol. xxii.

of the two former boilers—namely, 95, 105, and 112 lbs. pressure, that it may be accepted as the ultimate strain that boilers of this construction can bear after being twenty years in use. It is much less than that due to the formula usually given for a new boiler."

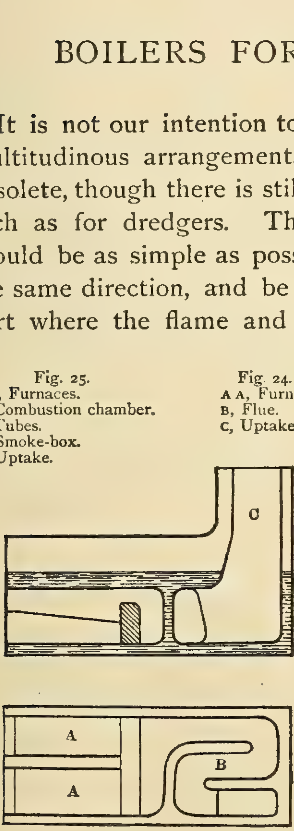
This boiler was twenty-five years old. Some of the plates and rivets showed little or no change, but brittleness appeared in the angle-iron.

BOILERS FOR MARINE PURPOSES.

It is not our intention to treat upon the old flue-boiler, with its multitudinous arrangements, as that class has now become nearly obsolete, though there is still a demand for them in particular cases, such as for dredgers. The arrangement of this type of boiler should be as simple as possible, and all the flues ought to run in the same direction, and be of uniform width, commencing at the part where the flame and gases meet from the furnace. When

Fig. 25.
A A, Furnaces.
B, Combustion chamber.
C, Tubes.
D, Smoke-box.
E, Uptake.

Fig. 24.
A A, Furnaces.
B, Flue.
C, Uptake.



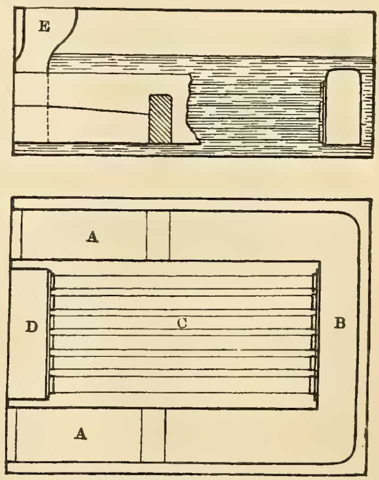
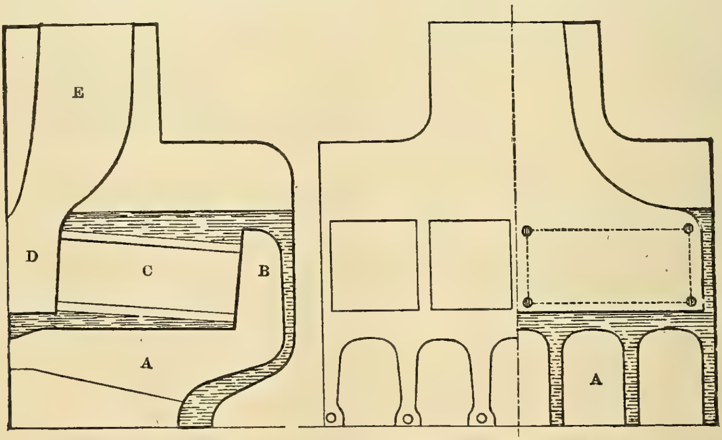


Fig. 24.—Flue Boiler for Dredger. Fig. 25.—Tubular Boiler for Dredger.
Longitudinal and Horizontal Sections.

more than one furnace is adopted all flues from the furnaces which join into one large flue should taper from the furnace farthest from the large main flue. This is obvious, as the flame and gases from that furnace mix with the next, and so on; care ought to be taken

that the main flue is large enough, and that the flame and heated gases do not meet in opposite directions. As dredgers generally work in harbours, where the water is very muddy, the mud being stirred up from the bottom by the action of the buckets, small tubular boilers should be avoided; the tubes should be at least 8 inches in diameter, with ample water space between them. The tubes in such cases are joined to the tube-plates, with a flange of angle-iron rivetted to the tube. In this example there are two furnaces, one at each side of the boiler meeting in a back flue, with return tubes at the same level as the furnaces. By this means ample water above the tubes, and a large steam space, are obtained. As it is an object to keep the weights low down, and as dredging vessels are generally shallow, a low boiler should be adopted, placed well below the deck, to give free passage fore and aft for the mooring chains, &c.

For ocean steam ships the multitubular boiler is decidedly the best, although some very good examples of flat flue overhead arrangements find favour. The tubes vary from 2½ inches to 4 inches in diameter; and in the merchant service they are placed over the furnaces on the return principle. When for moderate power, and



Longitudinal Section. Front Elevation and Transverse Section.

Fig. 26.—Ordinary Tubular Boiler.

A A, Furnace. B, Combustion chamber. C, Tubes. D, Smoke-box. E, Uptake.

arranged fore and aft, the boiler is generally made in one piece. Some of these boilers have no bottoms, but are simply fitted with a dry plate; while others, made in the usual manner, have dry plates laid on the bottom of the furnaces, thus preserving the rivet heads

from getting rubbed away by the mere friction of the tools for raking out the ashes.

Some boilers are constructed, as it were, back to back, in one large boiler. By this means two ends are saved, but the great weight of the mass deters many from adopting this plan; but where large power is required in small space, the arrangement has certain advantages. The stoke holes must be "fore and aft;" and in general the fore part of the boiler is the best steam producer, owing to the

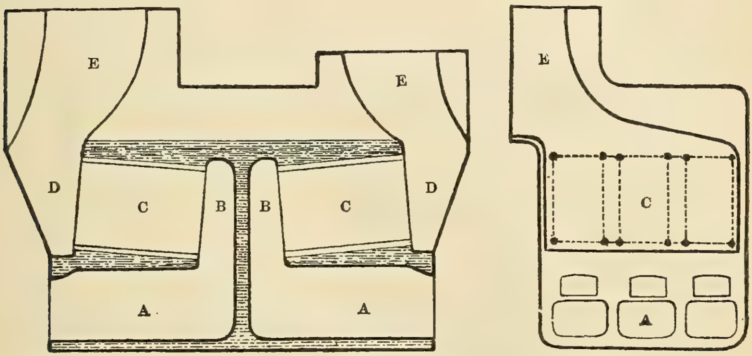
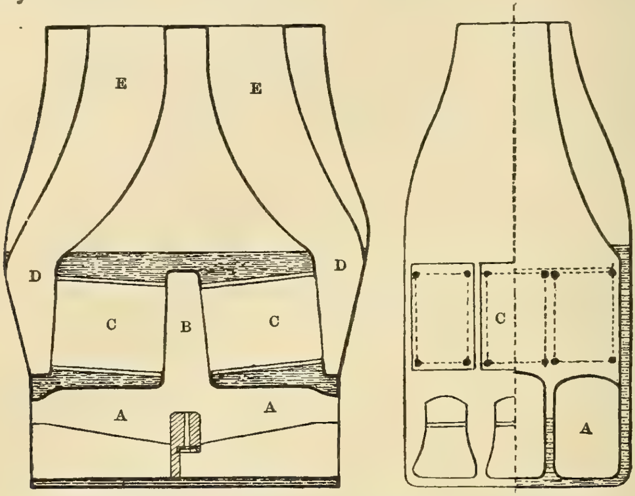


Fig. 27.—Double Boilers. Longitudinal Section and Front Elevation.
A A, Furnaces. B B, Combustion chambers. C C, Tubes. D D, Smoke-boxes. E E, Uptakes.

air getting better circulated in the stoke hole, but, with suitable air funnels from the deck, the aft furnaces of the boiler can be provided with the plentiful supply of air so necessary for combustion, and for keeping the stoke hole cool. There is a passage left between the two boilers, forming a communication between the fore and aft stoking-rooms; two funnels are fitted, and the general arrangement is best suited for paddle-wheel ships.

Another modification differs materially from the former example, having one combustion chamber common to both sets of furnaces. This will tend, in a great measure, to effect complete combustion, and the prevention of smoke; that is to say, if the furnaces are properly constructed and fired—the fore and aft furnaces being fired alternately, so that one fire is bright while the other is receiving fresh fuel. To assist combustion, air is admitted through the bridge, thus getting partially heated before mixing with the flame in the combustion chamber. These boilers are made high to insure ample steam room, while the large area of the uptakes inside of the boiler dries the steam. Indeed, some think this is by far the

best plan for superheating the steam; far before the complicated arrangements of separate superheating boxes, with the extra stop-valves, &c. In fact, dry superheaters soon get out of order, more especially when there is no steam in the boilers, as must be the case



Longitudinal Section. Front Elevation and Transverse Section.
Fig. 28.—High Double Boiler.
A A, Furnaces. B, Combustion chamber. C C, Tubes. D D, Smoke-boxes. E E, Uptakes.

for a considerable time when the fires are first kindled. Any one can fancy the flame acting on a thin tube, roasting, as it were, the steam, which subsequently dries up the lubricants, and soon plays havoc with the slide-valves, pistons, and cylinder faces of the engine. Steam is only partially dried in the best modern practice, and can be done in the boiler itself. It will be understood, in the boiler described, that two ends and two furnace backs are saved, the material being better disposed in the uptakes.

As we are dealing at present with low-pressure steam-boilers suited for the merchant service, we will draw attention to overhead flue arrangements. All boilers of this class should be so designed that every part is easily accessible for repairs; and, when properly constructed, we do not see why the flues should not last as long as any other part, and certainly boilers can be designed so that the flame and heated gases will pass up and down over a greater length of surface than in the plain tubular boilers. The flues in this example are the entire width of the boiler, leaving 6 inches of water space at the sides; the flame passes to the top of the combustion chamber at the back of furnaces, then dips downwards, and so on,

the flues being divided with suitable water spaces, and are strengthened at the top and bottom with conical tube stays, through which the steam rises and the circulation is effected. The water in the boiler is thus freely circulated, with the advantage of having a mode-

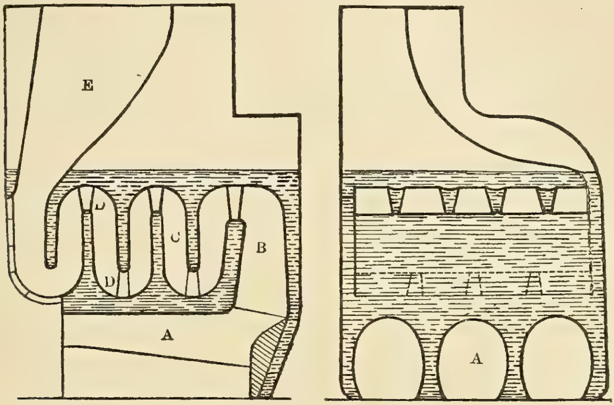


Fig. 29.—Overhead Flue Boilers. Longitudinal and Transverse Sections.
A A, Furnaces. B, Combustion chamber. C, Flues. D D, Circulating tubes. E, Uptake.

rate body of water, which, under certain circumstances, conduces to rapid evaporation. There are side doors at the bottoms of the flues for the convenience of cleaning them out, which can be done in some instances while the vessel is under way. Another form of flue

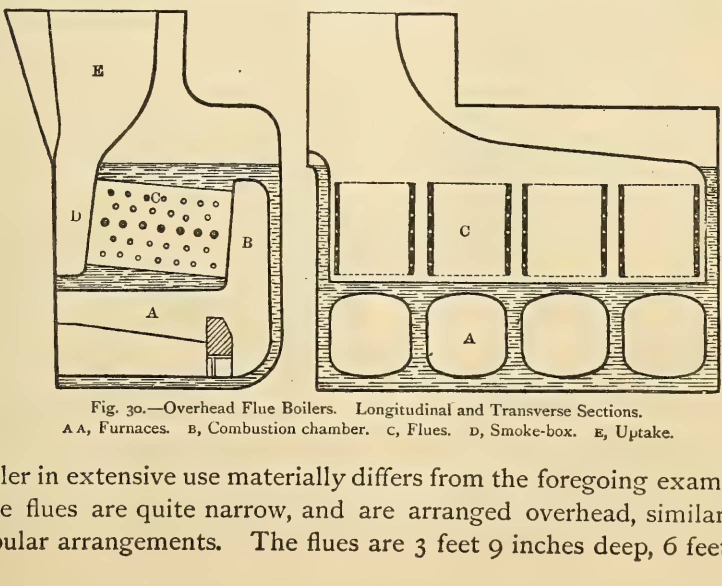


Fig. 30.—Overhead Flue Boilers. Longitudinal and Transverse Sections.
A A, Furnaces. B, Combustion chamber. C, Flues. D, Smoke-box. E, Uptake.

boiler in extensive use materially differs from the foregoing example. The flues are quite narrow, and are arranged overhead, similar to tubular arrangements. The flues are 3 feet 9 inches deep, 6 feet in

length, with 2 inches of space for the flame to pass through, and the pitch of the flues is 4¾ inches. They are formed of two parallel plates for the sides, with U-shaped pieces at the top and bottom; the side plates are flanged at the ends, as well as are the U-pieces at the top and bottom, for uniting them to the tube plates. The method of rivetting the top, bottom, and the sides together is as follows: the rivets are put through the holes, then wedging bars are placed in at the top and the bottom, and means taken to secure them in their places. Thus the rivets are firmly held in position, and are clenched quite cold; and when each section of the tubes are rivetted together they are placed between the tube plates, and firmly rivetted thereto. This kind of work requires to be carefully executed; for, should great leakage occur at sea, the tubes are not easily repaired. The flues are well stayed every 9 inches apart either way; these stays also act, to some extent, as heat conductors. When the work in this class of boiler is well executed it gives very little trouble at sea, which is essential in all marine steam generators.

The arrangement of low-pressure boilers for ships of war differs

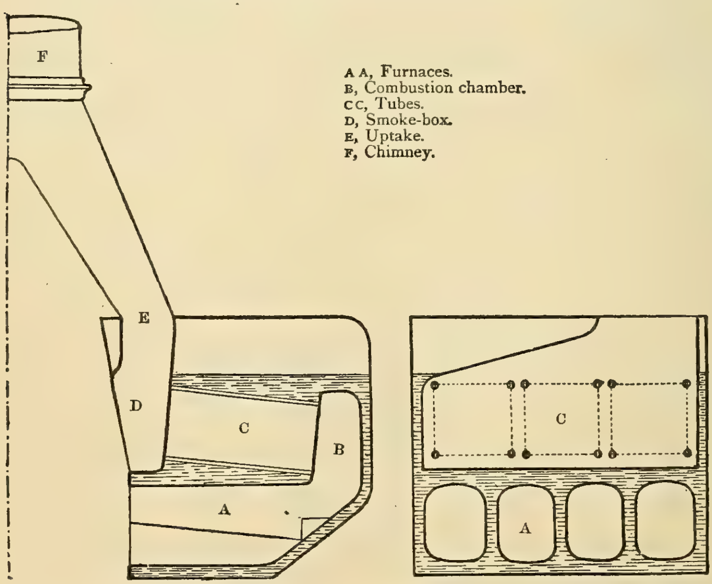


Fig. 31.—High Boilers, as arranged for the Royal Navy. Longitudinal and Transverse Sections.

from the tubular class adapted for the merchant service. There are two classes, namely, high and low, the former having the tubes

over the furnaces on the return principle, while the latter have generally the furnaces fore and aft, with the tubes athwart ship, the tubes reaching no higher than the tops of the furnaces. The best arrangement for the high class are furnaces athwart ship, with the stoke-hole between the boilers on the centre line of the vessel—the distance apart from front to front of the boilers being 10 feet; this is considered ample room for the firemen. As the top of the boilers requires to be at least 1 foot below the water line, the ordinary steam-chest is dispensed with, sufficient height being left between the top and the water in the boiler. To give free circulation fore and aft, the uptake or dry smoke pipe is shaped thus, Λ, flat at the bottom sides, but rounded at the top, to take the main funnel. This is a very good plan.

We have also seen many arrangements formed with the steam-chest over the firemen's heads; a plan that should never be attempted, as such require an artificial blast to keep free circulation in the stoke-hole, the usual plan being a fan driven by a separate engine; but in some classes of war ships, such as "Monitors," even this fan is necessary, the "free-board" in such ships being so low that in rough weather the hatches require battening down, and then ventilation must be kept up by mechanical appliances.

The low class boiler is admirably suited for fine midship sections, firing fore and aft. They are placed closely together at the centre line of the vessel, leaving only a space of 2 inches between the lagging, or the wood covering which is placed over the boilers to prevent radiation. The furnaces, say three in number, join in one "athwart-ship flue," widening from the furnace at the centre of the vessel to those at the sides, and then passing into the combustion chamber, which runs fore and aft, this chamber tapering from the furnaces to the extreme end. This

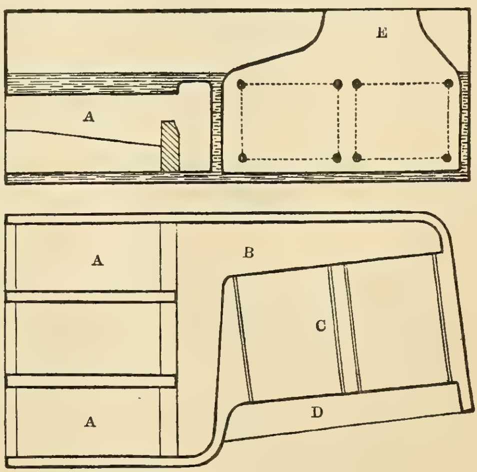


Fig. 32.—Low Boilers, as arranged for the Royal Navy. Longitudinal and Horizontal Sections. A A, Furnaces. B, Combustion chamber. C, Tubes. D, Smoke-box. E, Uptake.

is necessary, as the flame has always a natural tendency to take the nearest cut to the funnel: thus, when the combustion chamber is made wide at the furnaces and narrow at the extreme end the flame and gases are more equally distributed through the tubes. The tube plates are placed at an angle, for the convenience of getting out the tubes for repairs; and at the back, under the funnel, there is space left for cleaning out the tubes.

When the boiler space is rather limited, as in narrow vessels such as despatch boats, the furnaces are arranged fore and aft, with two furnaces at the centre of the ship, with separate combustion chambers for each furnace. This arrangement will suit best when the stoke-hole is forward, so that a current of air freely passes through, the air supply being greatly improved by the forward motion of the ship. The tubes are arranged at the sides on the return principle, but they are placed no higher than on a level with the top of the furnaces.

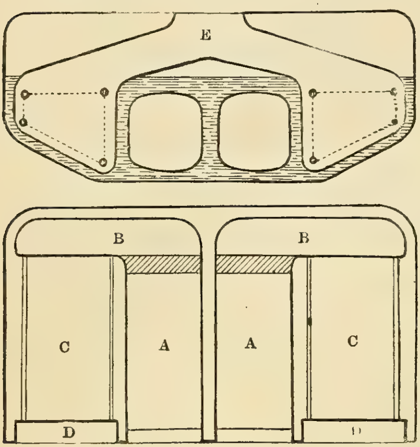


Fig. 33.—Low Boiler for Despatch Boats. Transverse and Horizontal Sections. A A, Furnaces. B B, Combustion chambers. CC, Tubes. DD, Smoke-boxes. E, Uptake.

The high and low pressure combined engines necessitate a stronger form of steam-generator, for which circular boilers are decidedly the strongest. One arrangement of double boiler has three furnaces at each end, the middle one being placed much lower than the two side ones; this is done to fill up the dead water space at the bottom. The furnaces are fore and aft, with one combustion chamber common to both; they are provided with dry uptakes fitted to the fronts. When four uptakes are arranged for one funnel, each boiler has a separate tubular uptake with a flue running through it. All the uptakes converge to the centre of the vessel; these uptakes serve the purpose of superheaters, and the inner tube, or flue, is strengthened with rings of angle-iron. For 300 horse-power nominal, the boilers being 13 feet 6 inches in diameter, the heating surface in each is as follows: 2308·88 square feet in tubes, 100 square feet in firebox, 248·22 square feet in furnaces, making a total for two double boilers, 5314·2 square feet, or 17·71 square feet per nominal horse-

power. So it will be seen that circular arrangements can be placed in almost as little space as ordinary marine boilers.

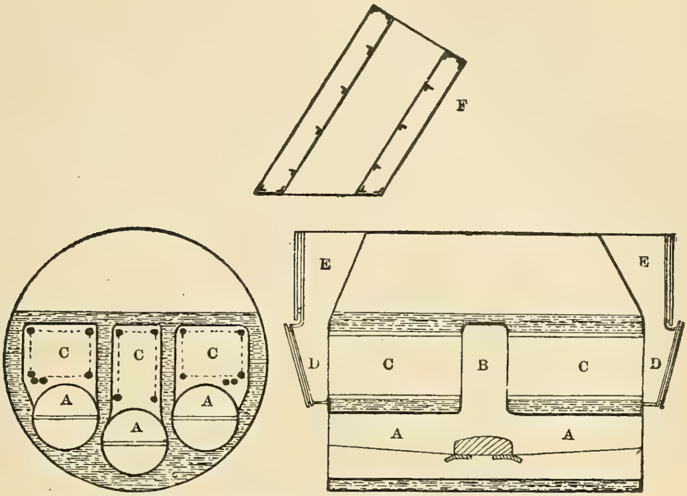


Fig. 34.—High-pressure Double Boilers. Transverse and Longitudinal Sections.
A A, Furnaces. B, Combustion chamber. C C, Tubes. D D, Smoke-boxes. E E, Uptakes. F, Separate uptake.

Some are arranged for only two furnaces in each single boiler, with tubes overhead as in the previous example, and having one combustion chamber common to both furnaces; this chamber at

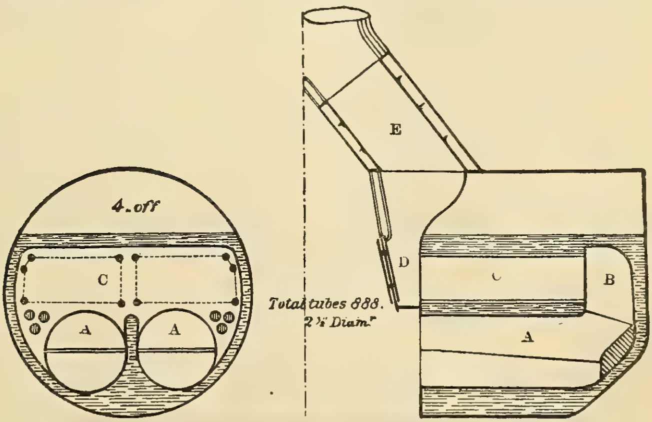


Fig. 35.—High-pressure Boilers. Transverse and Longitudinal Sections.
A A, Furnaces. B, Combustion chamber. C, Tubes. D, Smoke-box. E, Separate uptake.

the back of the furnaces is made large; indeed, in all boilers having tubes on the return principle the combustion chambers should

have ample capacity, so that the flame hangs, as it were, before passing through the small tubes, giving more time to abstract the heat from the gases before they pass up the chimney. This is more required when the uptakes in front of the furnaces are made dry, or separate from the body of the boiler, so as to keep the stoking-room as cool as possible. For moderate power, say 300 horse-power nominal, four boilers are adopted, with uptakes arranged for two funnels; and should the section of the vessel be very fine, with a great rise of floor, the back end can be bevelled or cut away at the bottom to suit the form of the ship. All the flat parts are stayed in the usual manner. For ships of war, when the stoke-hole is fore and aft, on the centre line of the vessel, the uptakes should form part of the boiler, as dry uptakes would make it intoler-

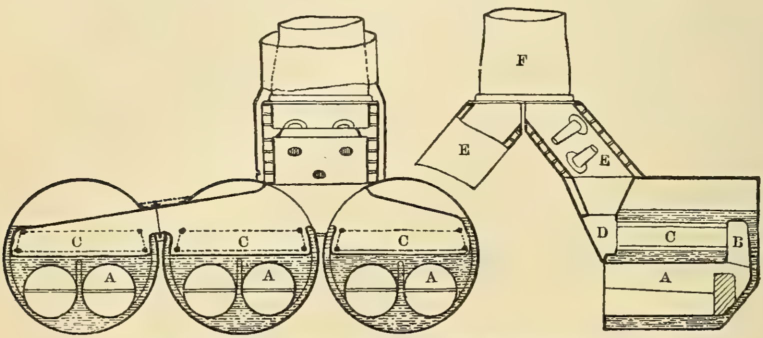
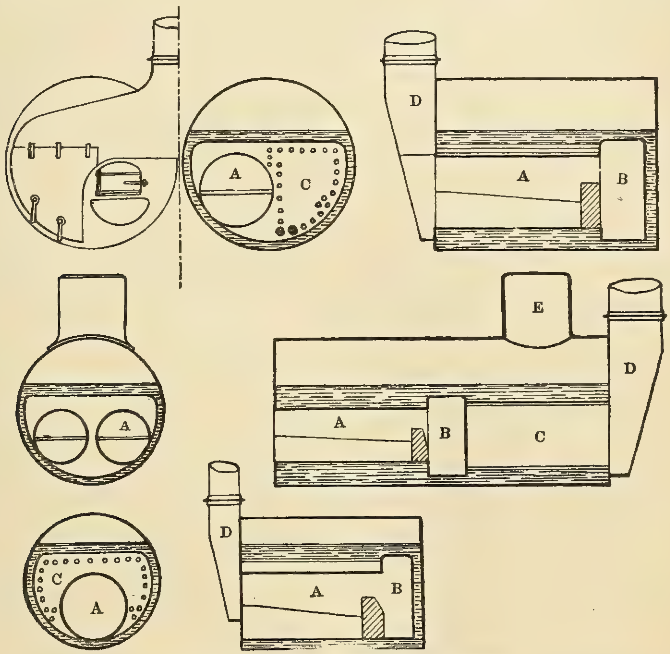


Fig. 36.—High-pressure Boilers, as arranged for the Royal Navy.
A A, Furnaces. B, Combustion chamber. C C, Tubes. D, Smoke-box. E E, Separate uptakes. F, Chimney.

ably warm for the firemen. The uptakes, or "lumleg," should be made double; they can be made slightly oval, and be strengthened with conical tubes, so that the steam freely passes through them; and when great steam pressure is demanded the insides and the outsides of the uptakes should be well secured with screwed stays; this arrangement will make a very effective superheater. The top of the uptakes must be below the water line. When one funnel is required for six boilers, it is placed centrally between the four front boilers, and the aft boilers have dry pipes, thus joining the three boilers on a side; the back of the boilers at the bottom are cut away to suit the form of the ship, but when this is not required they should be straight, thus simplifying the construction. The up-takes must be fitted with the usual outer casings, for taking away the vitiated atmosphere from the stoking-rooms.

For small power for great steam pressure, one furnace is fitted with return tubes at the side; while other boilers have the furnace central with the boiler, with return tubes overhead and at each side. The lower tubes in such an arrangement should be larger; thus the flame is drawn down, as it were, and the bottom tubes by this plan are kept free from soot deposit. Another arrangement has two furnaces in each boiler, with the combustion chamber at the back of the furnaces, and then the tubes placed direct through the boiler, thus entailing a long boiler; and this plan is good when there is



Figs. 37, 38, 39.—Small High-pressure Boilers.
A, Furnace. B, Combustion chamber. C, Tubes. D, Dry uptake. E, Steam dome.

sufficient room in the vessel. When a steam-chest can be fitted, it is preferable to do so; and it is found a great advantage in such small boilers to line the combustion chamber with fire-bricks, having apertures for the smoke to freely pass. The steam pressure usually adopted is from 40 to 60 lbs. per square inch, and such boilers are best suited for river navigation, where good fresh water is obtained.

As some river boats are made very shallow, and constructed of very light scantling, it is desirable to have the boiler, and all the machinery, designed to spread over a large surface; and when

100 lbs. steam pressure is used, boilers of the locomotive type are decidedly the best, and they can be made of steel, thus tending materially to increase the carrying power for cargo by lightening the boiler. The same class is largely used for steam-launches, having the whole of the machinery fitted thereto.

Torpedo boats are now fitted with the locomotive type of boiler, carrying a working pressure of about 120 lbs. per square inch. The draught is forced by a fan blast. The evaporation in these boilers per lb. of coal seems to be about 7 lbs., and the evaporation per hour per square foot of heating surface varies from 11 to 18 lbs. The coal consumed per hour per square foot of grate varies from 50 to 100 lbs.

The haystack boiler, originally introduced in Clyde river practice, is well suited for vessels of light draft. The shell is cylindrical with a dome-shaped top. The tubes are placed vertically, with the furnaces beneath and around the sides.

PROPORTIONS FOR MARINE BOILERS.

When a number of boilers are to be designed of various sizes, it will facilitate the designer if he fixes on the scale to be universally adopted, and get the drawing-paper prepared with light lines, ruled in 2-inch squares, according to the scale determined on, these squares corresponding to the pitch of the rivets, or 2 inches between centre and centre. It is by far the cheapest and best arrangement where the front and the sides are worked square at the corners, the back at the top and the bottom being rounded, as in many instances this requires to be done to fit the midship sections of the vessel. Boilers so designed, and drawn on ruled paper, greatly assist the draughtsman in getting up the working drawings for the workshop.

After making a rough sketch of a boiler, we know about the length, breadth, and the height required, and commencing on the side of a square, we lay off the length, breadth, and the height per scale; thus the configuration of the boiler is represented by so many squares; the length, breadth, and the height should always be even dimensions, and there is nothing to prevent all boilers being so constructed. We may now set out the plating, taking the centre of the squares as the edges of the plates, wherever we arrange the joints, breaking bond where required. It is evident that the plates must be always of even dimensions. Each plate will contain as many rivets, of the universal pitch of 2 inches, as there are squares; thus by

counting the number of squares in each line of plating in the length and the breadth we arrive at the true length and breadth of each plate without using a scale, the ruled paper being the universal scale for all flat surfaces; all the other parts of the boiler where practicable should be set out in like manner, and after they are marked on the drawing No. 1, No. 2, &c., these are the marks that must be numbered on each plate as delivered from the rolling-mills. No. 1 plate will contain so many rivets in the length and breadth, thus the machinemen need never apply a foot-rule, but simply adjust them on the travelling table of the drilling or punching machine, and the machine itself will do the work of drilling or punching the plates with mathematical precision, the plates being previously planed on the edges to the correct size.

In all Government contracts the top of the boiler must be at least 1 foot below the water line. To insure ample steam room 3 feet 6 inches is allowed from the top of the boiler to the top of the flues. For boilers intended to run out about four times the nominal horse-power make an allowance of ·68 to ·7 of a square foot of fire-grate surface, per nominal horse-power, and from 18·8 to 19 square feet of heating surface, taking the whole circumference of the small tubes that in multitubular arrangements is available, including the flues, sides, and the tops of the furnaces above the fire-grate, and one half of the back tube-plate may be included in the total heating surface. Composition tubes are usually adopted, having an external diameter of 2½ to 3½ inches, and the pitch of the tubes 3½ to 4¾ inches. The length of the tubes may vary from 5 feet 6 inches to 7 feet, but should never exceed that length.

Fire Grate and Heating Surface for Indicated Horse-power.—For every indicated horse-power the engine is intended to work at, make an allowance of about 3 to 3½ square feet of heating surface, and one-eighth of a square foot, or 18 square inches, of fire-grate for every horse-power indicated. The consumption of coal per square foot of grate is about 20 lbs. per hour, and the water evaporated about 9 lbs. per lb. of coal.

Writing on this subject, Professor Rankine gives as follows:—"The greatest available heat, or the rate of expenditure of heat upon the steam, is to be compared in units of work, by dividing the greatest indicated power required in units of work, per unit of time (say in foot-pounds per hour), by the probable efficiency of the engine; or, otherwise, multiply the pressure equivalent to the rate of expendi-

ture of heat by the total cylinder capacity, and by twice the number of revolutions per minute.

FIRST METHOD.

Probable indicated power,..	743
× foot-pounds per hour (in indicated horse-power),.	1,980,000
	1,471,140,000
The above divided by the probable efficiency of the steam, 0·12, gives the available heat required in foot-pounds per hour,.........................	=12,259,500,000

SECOND METHOD.

Estimated pressure equivalent to rate of expenditure of heat in steam (lbs. on the square inch) $108\frac{1}{3}$ × estimated total cylinder capacity in prism of 1 foot × 1 inch × inch by twice the number of revolutions per hour,..	39,033
	4,228,575
	28,992
	12,259,484,650

"*Available Heat required in foot-pounds per hour.*—The available heat of combustion of 1 lb. of fuel (or rather coal) is to be estimated by multiplying the total heat of combustion of 1 lb. of fuel by the efficiency of the furnace.

"The total heat of combustion of 1 lb. of coal of a good quality for marine purposes may be estimated at from 9,000,000 to 10,000,000 foot-pounds, and that of the very best at 12,000,000 foot-pounds. Inferior qualities about two-thirds of the above estimates.

"The efficiency of the furnaces may be roughly estimated as follows—Divide the intended number of square feet of heating surface per lb. of fuel per hour, by the same number + 0·5, eleven-twelfths of the quotient will be the probable efficiency nearly. The following are examples:—

	Square Feet Heating Surface per Lb. of Fuel per Hour.	Efficiency of Furnace.	Available Heat per Lb. of Coal of Total Heat, 10,000,000.
Small Value for Marine Boilers......	0·50	0·46	4,600,000
Ordinary Values in Marine Boilers	0·75	0·55	5,500,000
	1·00	0·61	6,100,000
	1·25	0·65	6,500,000
	1·50	0·69	6,900,000
	2·00	0·73	7,300,000
Water Tube and Cellular Boilers,	3·00	0·79	7,900,000
	6·00	0·84	8,400,000

"The most common values of the available heat of a pound of good

steam coal in marine boilers are 5,000,000 to 6,000,000 foot-pounds, making an allowance of 20 to 50 per cent. for waste, &c.

"To find the probable greatest rate of consumption of fuel, divide the available heat per hour by the available heat of combustion of 1 lb. of fuel (example) available heat per hour, 12,260,000,000 $\div$ available heat of combustion per lb. coal, say 5,500,000 = 2229 lbs., probable consumption of fuel per hour.

"To find the proper area of heating surface, multiply the rate of consumption of fuel in pounds per hour by the intended area of heating surface to each pound of fuel per hour, that is usually from $\frac{3}{4}$ to $1\frac{1}{2}$ square foot.

"To find the proper area of fire-grate, divide the rate of consumption of fuel in pounds per hour by the weight of fuel in pounds to be burned per hour on each square foot of grate, the quantity ranges in ordinary boilers from 16 to 12 lbs., and the latter limit may be considered a suitable rate for the most rapid combustion at high speed, provided air is admitted above the fuel to burn its gaseous constituents. In some grates the combustion is as low as from 6 to 12 lbs.

"The total sectional area of flues (or tubes) is from one-fifth to one-seventh of that of grate, the area of the chimney one-tenth of that of the grate.

"The capacity of marine boilers is equal to the heating surface multiplied by about 1 foot for flue boilers, or 0·625 of a foot for tubular ones (exclusive of furnace room), including all internal parts; the contents may be estimated as nearly equal to the area of fire-grate multiplied by from 6 to 8 cubic feet, one-fifth being steam-room, and the rest partly water space, &c."

The following are some of the relations which exist in recent marine practice:—

Grate Surface in square feet = Nominal Horse-power $\times \frac{3}{5}$.
Heating Surface in square feet = 25 to 28 times the Grate Surface.
And $\frac{5}{6}$ths of the total Heating Surface = Tube Surface.

$$\text{Or Grate Surface in square feet} = \frac{\text{Indicated Horse-power}}{8};$$

And Heating Surface in square feet = Indicated Horse-power $\times 3\frac{1}{2}$.

Staying.—Flat surfaces, such as for low-pressure marine boilers, must be strengthened with a suitable number of stays. The distance between the stays may be 18 inches for pressures below 20 lbs. per square inch, but for pressures above 20 lbs. per square inch, the

distance between should be 16 inches, in the parts that require periodical inspection, but in confined places where it is not easy of access 14 inches between the stays may be adopted. As corrosion rapidly sets in, the stays must be made of greater strength, in the first instance, than what is actually required; and it is advisable that all the stays should be rivetted to angle-iron secured to the boiler, palms or flat pieces being forged on the stays for taking the rivets. By this plan the angle-iron materially stiffens the sides of the boiler. When the sides of the boiler are stayed with round bar-iron, screws are formed at each end, the diameter at the bottom of the thread being the same as the main body of the bar: thus the ends being larger than the bar, are more easily passed through and through. These stays have nuts on the outside and inside of the plates, with washers for screwing the nuts against: by this means the plates can neither bulge out nor collapse. The sides of the furnaces and water spaces all round the combustion chamber at the back of the boiler have screwed stays similar to a locomotive boiler. These stays are simply short bars of iron, screwed from end to end, the plates being tapped to receive them, so that when they are screwed into the two plates, each bar forms a secure stay to resist bulging and collapsing; and as they require to be at times removed they are not rivetted as in the locomotive boiler, but merely fitted with nuts on each plate. The stays for the sides of the furnaces should be well kept out of the fire; they can generally be so arranged that the top rows are above the live coal, as high up as convenient, and the bottom rows entirely below the fire-bars. The tube-plates should be properly stayed. Some makers prefer using tube-stays, well screwed at the ends and fitted with outside and inside nuts. Sometimes collars are formed on the stay-tubes for the inside, and nuts on the outside. This is not a very good plan, for should anything happen to a tube, there is a difficulty in taking it out, and it is evident that it cannot be replaced. The best method of staying the tube-plates together is by sacrificing some of the tubes as heating surface, and staying with plain round bars screwed at the ends, with nuts inside and outside of the plates. Although for the working parts of marine engines, and all parts subjected to tension, 4000 lbs. per square inch is allowed for wrought-iron, it is advisable for the stays only to allow about 3000 lbs. per square inch. We will now run out the number and diameter required in a flat-sided boiler, supposing the side is 10 feet by 11 feet, and say 56 stays can be conveniently got

in. Find the number of square inches in the surface, multiply by the pressure per square inch, say 20 lbs.; thus, $10 \times 11 \times 144 = 15{,}840 \times 20 = 316{,}800$ lbs., equal pressure on the whole surface, which, divided by 3000, gives the total area of the stays; and again by 56, gives the area in square inches for each stay at the bottom of the thread: $\frac{316800}{3000} = 105{\cdot}6 \div 56 = 1{\cdot}8$ square inch area for each stay, say 1½ inch in diameter. For the screwed stays in the furnace side-plates the diameter is generally 1¼ inch, with spaces to suit; and the stays which secure the sides and bind the top and bottom together—*i.e.* the stays passing through the water spaces between the small tubes—are made of flat bar-iron, with screwed ends and nuts inside and out.

Fire-bars.—Wrought-iron fire-bars have a breadth of 1⅜ inch at the top and ½ inch at the bottom, and are 3 inches deep.

Weight of Wrought-iron Bars,	3 ft.	3 in.	long	= 30 lbs.
Weight of Cast-iron Bars,	2	0	,,	= 19
Weight of do.	2	6	,,	= 24
Weight of do.	3	0	,,	= 27·5
Weight of do.	3	6	,,	= 32·0
Weight of do.	4	0	,,	= 36·5

Cast-iron bars have a breadth of full ⅞ inch at the top and full ½ inch at the bottom, the depth ranges from 3 to 4½ inches, and the distance between bars from ⅜ to ½ inch.

Tube Area, Furnaces, &c.—The calorimeter of the boiler or sectional area of the tubes is a subject no one need trouble himself about, as the combined area of the tubes is greatly in excess of what is required, and in which we have no choice, as it depends on the length of the tubes that can be introduced. The ordinary size of tubes for the merchant service varies from 3 to 4 inches external diameter, and from 6 feet to 7 feet in length; while for the Royal Navy the tubes are 2½ to 3½ inches external diameter, and 5 feet 6 inches to 7 feet in length, consequently it will be seen that the longer the tubes are the greater the heating surface, while the combined area through them may be the same. The only thing to be considered is to arrange them so as to get the greatest effect from the fuel. For the Royal Navy composition tubes are usually adopted, as their conductive power is greater, and the water spaces are not so liable to choke up with deposit; but for the mercantile marine iron and steel tubes are extensively used. The tubes in either case are driven hard into the holes in the tube-plates, and, after they are all in their places, are widened out with a suitable tool, and the edges neatly laid over.

Sometimes ferrules are fitted and driven into the tubes nearest the furnaces, but at the smoke-box end they are simply expanded, and a slight countersink left in the holes on the outside, thus forming a collar when the ends of the tubes are laid over. The flues and combustion chamber at the back of the boiler are of great importance, more especially with short tubes arranged and worked on the return principle. In many boilers of this class the flame and heated gases pass too rapidly through the boiler into the chimney, and if not fitted with a high uptake causes great waste in fuel, the flame and gases having little time to act on the heating surface. The combustion chamber should be made large, so as to make the flame hang in the flues before passing through the small tubes. The usual size at the top of the combustion chamber is 18 inches, and at the bottom 22 inches, from the tube-plate to the back of the chamber, this being actually required in all cases to properly expand and lay over the ends of the tubes. It is advisable, however, not to increase this space to any great extent, more especially for high pressure, as large flat surfaces are not to be desired. But for moderate pressure, 22 inches at the top and 26 inches at the bottom will tend to retard the flame and gases in the combustion chamber. The area over the bridges is from 18 to 19 square inches per nominal horse-power; thus it will be seen that the calorimeter of the tubes is greatly in excess of this. It must be acknowledged by all that marine boilers should have as many furnaces as possible, bearing in mind that there is a certain size of furnace very convenient to manage, and other sizes, above or below, that are not so convenient. A good medium is a width of 2 feet 9 inches, and certainly not less than 2 feet 6 inches, or greater than 3 feet 3 inches, and from 6 feet to 7 feet in length, but should not exceed the latter, as a 7-feet furnace is quite long enough to manage properly. But in some instances the boiler room is so limited that length must be substituted instead of breadth. Some makers have even gone to the extreme as regards the width, considering if they make the furnace circular, a diameter of 3 feet 6 inches could be used with impunity; but experience proves the contrary, as with ordinary sea water scale will form, and accumulating to any great thickness, the furnace plates become heated and the tops come down, even although there is a plentiful supply of water in the boiler. So as many furnaces of a medium width as can be conveniently arranged are far better than a less number of a great width, considering the more furnaces we have there will be more side surface

exposed to the action of the fire; for undoubtedly at the tops and sides of the furnaces the water is most rapidly evaporated, and consequently a better steam-producing boiler will be obtained,—a result that all should strive to reach, even although it may be at considerably more cost in manufacturing.

Thickness of Plates for Round Boilers.—As these boilers, for the compound marine engine, are made large in diameter, carrying high steam pressure, the best quality of iron must be used, or B, B, equal to Yorkshire plates, the breaking strain being 57,120 lbs. per square inch; and taking one-fifth of the breaking strain of the plate or rivetted seams as the constant for this quality of iron, we have—

$$\frac{D\,P}{11424} = \text{thickness of the shell.}$$

Thus, supposing we have a boiler 142 inches in diameter, and the steam pressure 70 lbs. per square inch—

$$\frac{142 \times 70}{11424} = .87 \text{ or } \tfrac{7}{8} \text{ inch thick.}$$

The seams should be double-rivetted, which are nearly equal in strength to the solid plates. For the thickness of the plates for the other parts of boilers we give two examples by English and Scotch firms, the steam pressure being 70 lbs. per square inch in each case:—

	London Made. inches.	Leith Made. inches.
Diameter of Boiler	142	120
Thickness of Shell	$\frac{7}{8}$	$\frac{11}{16}$
Do. End Plate	$\frac{3}{4}$	$\frac{11}{16}$
Do. Tube Plate	$\frac{3}{4}$	$\frac{11}{16}$
Do. Furnace Plate	$\frac{7}{16}$	$\frac{7}{16}$
Do. Back of Furnace Plate	$\frac{7}{16}$	$\frac{7}{16}$

Strength of Flue Tubes to resist crushing. Example:—

$$\frac{.43^2 \text{ inch thickness of plate} \times \text{constant } 700000}{7.25 \text{ feet length of tube} \times 36 \text{ inches, diameter of tube}} =$$

ult. strength 495 ÷ 6th = 82 lbs. working pressure.

In a paper on the Strength of Boilers, by Mr. J. Milton, surveyor to Lloyd's,[1] the question of factors of safety is considered; and it is shown that the ordinary cylindrical boiler is the only really reliable marine boiler at present in use, and that as the shell plates had reached up to a thickness of 1¼ inch, the weight of such a boiler became an important item in the load carried by the ship. Hence,

[1] See *Trans. Inst. Naval Architects*, session xviii.

any method whereby the boiler could be lightened, and yet kept efficient, would be of great value for mercantile purposes. It is shown that Prof. Rankine and others estimate that a factor of safety of *eight* is necessary for such a *live* load as steam. The author however, states, "Now experiments show conclusively that up to a temperature considerably exceeding that at which it is practicable to use steam, wrought-iron does not lose strength; and as no part of a properly designed boiler is subjected to a temperature much greater than that of the steam within it, without being specially strengthened, there does not appear to be any reason for this great difference of factor of safety. The Manchester Steam Users' Association, founded by Fairbairn for the prevention of boiler explosions, consider that where boilers are well built and carefully examined periodically a factor of safety of *four* is sufficient, and the correctness of these views is shown by the freedom from accidents in boilers guaranteed by them; but of course we are not warranted in concluding from this that the same factor would be sufficient for marine boilers, which often cannot be subject to the same careful and systematic examinations as land boilers. The old-fashioned box boiler working at from 10 to 30 pounds had only a factor of about *four*, and yet the accidents which have happened with this low factor of safety were quite as few in proportion to the number of boilers in use as with the higher factor of *six*, which is about the present practice of the country, although at the same time improved appliances have enabled boiler-makers to make better and more reliable work than formerly. But although the present factor of safety is nominally *six* in many boilers which are at present at work, there are parts which, either from oversight or want of knowledge on the part of their designers, are very much weaker than the other parts, and which considerably reduce the actual factor of safety. Yet we find that these specially weak parts are often quite strong enough for their work, for even after many years' service they do not show any signs of weakness. If these parts are strong enough, then undoubtedly the extra strength of the remainder of the boiler has been so much useless weight."

On the question of proportioning the strength of boiler, the effect of expansion is pointed out as an important agent in the tear and wear of a boiler. "There are certain strains which boilers are subject to which are, under certain conditions, much greater than any which the working pressure can bring upon them, and which are

altogether independent of the factor of safety employed. I mean the strains brought upon the boiler by the unequal expansion of its different parts. Ordinary wrought-iron plates, if left free from stress, expand ·0000064 of their linear dimensions for each degree Fahr. increase of temperature. Also if the plates are subjected to stress they alter in length a certain amount according to the quality of the iron; the more ductile irons altering more for the same amount of stress. Taking as the mean value of E, 29,000,000 (the value given by Rankine) we find that a stress of 186 lbs. per square inch will give the same alteration in length as 1° Fahr. If, now, the ends of a plate are rigidly fixed so that it is incapable of altering its length, an increase of 1° Fahr. will subject it to a compressive stress of 186 lbs. per square inch, and a decrease of 1° to a tensile stress of equal intensity; and it is to be observed that these stresses are totally independent of the sectional area of the plate. Now, in the case of a furnace, the portion above the fire, especially when coated with even the thin enamel or scale which is necessary to preserve it from corrosion, must be considerably hotter than the portion below the bars. Hence the top of the furnace tends to get longer than the bottom. If the end fastenings of the furnace were so rigid as to maintain the top and bottom of same length, the top would have to be compressed and the bottom stretched, and every difference of a degree Fahr. in the temperature would produce a compressive stress in top and a tensile stress in bottom of 93 lbs. per square inch. But actually the end fastenings are not so rigid, and the strains caused by the unequal expansion are not distributed from top to bottom by the ends only, but also in a great measure by the resistance to shear of the plate, and hence the greatest stresses come at the middle of the length of the furnace. Also, it is evident that these strains are not uniformly distributed, and hence their maximum must be greater than their mean, and with a great difference of temperature the stresses reach a high figure. The only way to strengthen furnaces from such strains is either to prevent the difference of temperature, or else to allow the crown freedom to expand."

The question of reduction of strength of plates by punching or drilling has had much attention, and experiments go to prove the greater strength of drilled plates. Steel plates should always be drilled; if punched, they must be annealed afterwards to reduce the local strains set up by the action of the punch.

The corrosion of boilers is an important matter, and recently since

the introduction of steel the question has been raised as to the relative resistance of the iron and steel plates to this action. So far as experiment or experience has gone, the action seems to be pretty much the same in both materials. The influence of scale upon the steel plates is prejudicial, as a galvanic action is set up between the part covered with scale and any parts not so covered, which causes pitting of the latter. This scale of black oxide can be removed by exposure to acid, and in ships building at present for H. M. Navy the plates are immersed in a solution of sulphuric acid and water so as to clear away any scale which may adhere to them.

Where certain kinds of peaty water is used for feeding, the boiler seems to be quite unaffected by corrosive action. This is notably the case in the boilers of the Loch Lomond steamers, some of which after very many years' service are unaffected by corrosive action. It appears that a kind of coating, of a dark or brownish colour, is deposited on the iron, which protects it, and does not appear to affect the conducting power of the plate.

One method of bringing about the much to be desired lightening of boilers is to adopt the locomotive type of boiler with forced combustion. This method is now tried in steam launches, or torpedo boats, where as much as 150 lbs. of fuel appears to have been burned per foot of grate per hour.

In reference to this question of economy of weight, *The Engineer*, in a leading article, July 8, 1881, says—"The modern high-pressure marine boiler is by no means all that a boiler should be. We may take as a type a three-furnaced boiler to carry 70 lbs. Such a boiler will be about 12 feet in diameter by 10·6 feet long. It will contain three furnaces, each three feet in diameter, and a little more than 7 feet long, and each furnace will have a separate back uptake, and sixty 3-inch tubes 7 feet long. A boiler of this kind, if fitted with a large steam dome, will steam well, and may be depended upon, with fair coal, to work a pair of compound engines up to 500 indicated horse-power. Its shell plates will be nearly 1 inch thick, and its total weight without water will be roughly 28 tons, and it will hold 14 tons of water. Its gross weight therefore will be, under steam and allowing for grate-bars, &c., not far short of 45 tons. It will have a grate surface of about 57 square feet, a tube surface of 900 feet, the crowns of the furnaces will amount to about 100 square feet, and the uptakes may be taken as 120 feet more. The total heating surface will be therefore a little over 1100 square feet.

"If we contrast this with a locomotive boiler, we find that the latter will not weigh, complete with water and in working order, more than 12 or 13 tons. It will have 1100 feet of heating surface, and 18 to 20 square feet of grate, and it may be depended upon to develop 600 horse-power in a non-condensing engine.

"The cubical space occupied by the locomotive boiler will not be more than one-fourth of that taken up by the marine boiler, and it will be on the whole quite as economical, if not more economical." In referring to objections to the use of the locomotive type of boiler at sea, it is pointed out that a fair trial has not yet been made of such boilers at sea for mercantile purposes, and that it has proved serviceable in torpedo boats.

Attempts are being made at present to give practical effect to this question of decreased dead weight by reducing the diameter of the shells, and giving increased draught so as to consume more fuel per foot of grate surface.

As to the question of the relative economy of chimney draught and forced draught, it has to be borne in mind that although power has to be expended in driving fans or blowers to produce a forced draught, still in the chimney draught a large proportion of the heat of the furnace is spent to produce and keep up such draught, reaching, according to some authorities, to one-fourth of the available heat of combustion.

It has been proposed to carry out forced draught by jets of steam in funnel or air in ashpit, or by fans blowing air into ashpit direct, or into the stoke-hole, the latter in this case requiring to be air-tight.

Funnel, Damper, &c.—The ordinary height of funnels for steamships of the merchant service is about 32 feet 6 inches from the top of the steam-chest, and about 48 feet height from the top of the fire-bars, the area $= \frac{1}{6}$th of fire-grate. Where more than one funnel is required the arrangement of the boilers will determine the number and positions of the funnels. It is very usual now in large ocean-going ships to have two funnels, and in some cases even three funnels, as the *City of Rome*, *Livadia*, and other vessels. In the first-named ship the funnels are arranged fore-and-aft, in the *Livadia* athwart-ships. The plates are generally arranged in four lengths, the three lengths towards the bottom 9 feet each, and the top plates 5 feet 6 inches. The joints are butted, with strips inside of the chimney, and the circumferential joints are

made with a flat ring and iron moulding. At the top horizontal joint, or 27 feet from the bottom of the funnel, lugs are forged on the ring, on which to fix links for the funnel shrouds, which are secured below to the side of the ship.

Thickness of Bottom Plates,..............................	$\frac{3}{16}$ inch.
Do. of Top Plates,..................................	$\frac{1}{8}$,,
Joint Straps,...	$4\frac{1}{2} \times \frac{7}{16}$,,
Flat Rounded Moulding,..................................	3 inches.

The bottom of the funnel is fitted to a cast-iron ring secured to the top of the steam-chest. Where four boilers are used this ring is divided into four parts, with cross bars of cast-iron, cast in one piece, to which is fitted a damper for each boiler, having an uptake from each, independently of the others, that the draught of each boiler may be regulated separately. One of the cross bars is cast hollow, forming a pipe from the side to the centre of the ring, or centre of the funnel; this is termed the blow-pipe, and is fitted with a plug-valve in connection with the steam-room in the boiler. The engineer by this means can urge on the fires by blowing the steam up the chimney, and thereby causing a partial displacement of the air, which is filled up by the atmospheric air rushing under the fire-bars and through the holes left in the furnace doors, providing the large supply of oxygen so necessary for combustion. With high-pressure engines the waste steam from the cylinders is blown up the chimney in a manner similar to the blast-pipe of the locomotive engine.

Funnels of large diameter are usually stayed internally with round bar iron, to prevent them from getting out of shape in the workshop or on carriage to the ship. For ships of war the funnel is made telescopic, the top part sliding into the lower part. The outside part, or lower portion, is formed conical at top, with a corresponding cone for the internal or top portion, fitted at the bottom. Thus, when the top part is hoisted up, the inside cone fits into the outer one, and the funnel is screwed hard up with set screws, swivelling in boxes recessed in the funnel. The points of the screws bear on an angle-iron, fitted round the outer portion. The top part has likewise the shrouds for securing the funnel to the ship's side. The mechanism for hoisting up the funnel is a worm-wheel and pinion, with the necessary barrels, chains, and guide blocks. This gear should, when possible, be fastened down to the top of the boilers, or strongly bolted to the side plates of the bunkers, as the worm-

wheel is apt to jam in the pinion if the frame for it is not rigidly secured. An outside air-casing must be carried up from the top of the boiler, or dry uptake if so fitted, to about 8 feet above the deck, for taking away the vitiated air from the stoke-hole, and protecting the woodwork of the combings around the funnel from the great heat radiated from the uptake. On the deck there is another casing, so as effectually to keep the passage round the funnel cool. There are holes all round at the tops of the casings, and likewise at the bottom, for the thorough ventilation of the stoke-hole. The waste steam-pipe is likewise made telescopic, the bottom part having a suitable stuffing-box, through which the top part slides steam tight, the top part having a stay, with collars on the waste-pipe, the stay being attached to the top or sliding part of the main funnel.

The smoke-doors should be hinged to flat bars, fastened vertically to the smoke-box. The doors should have an inside plate and an outer one, kept apart from the door itself, but secured to it by ferrules and rivets: the inner plate is to protect the door from the fire, and the outer one to keep the stoke-hole cool. By this arrangement a current of air passes freely between both the inside and the outside plates. There are handles, fitted with a means of keeping the door shut, so constructed that the sneck or snib presses the door forcibly against the hinge plates. The furnace doors are hinged so as to cover the apertures formed in the front plates, thus doing away with cast-iron frames, and are pierced with air holes, having the means of regulating the supply of air to the furnaces. The ashpits are fitted with dampers at front, hinged on a pin, having ratchet wheels and pawls, for regulating the supply of air underneath the bars, or, by shutting them, damping the fires. The manhole on the top of the boiler should be cut in the most convenient place, and the door secured on the outside with a bridge piece, strongly bolted. The size of the manhole is usually 18 inches by 14 inches, which is sufficient to allow a man of ordinary size to pass through for inspecting and cleaning the inside of the boiler. Smaller doors are left in the front plate of the boiler, between the furnaces at the top, of sufficient size to allow a boy to pass through for scaling the furnace tops. All the necessary doors must be fitted at the bottom of the boiler, for raking out the sludge, the bolts for securing them being made so as to draw up the door against the inside of the front plate of the boiler; one large bolt, having a cross bar over the hole, is by far the best plan for securing them.

Of late years many improvements have been made in connection with steam boilers, with the view of increasing the economy of the fuel, and thereby rendering the boiler a more efficient steam-generator. The loss due to emission of smoke may in many cases be met by careful firing. Appliances known as mechanical stokers have been introduced, whereby the fuel is gradually fed to the furnace through a hopper arrangement in front, means being adopted to work the coal to back of furnace. Another method of fuel feeding has been recently tried, in which the coal is charged upon a movable truck, which by gearing is pushed inside the grate and below the fire-bars, the fresh coal is then lifted or pushed up below the burning fuel, and thus partially cokes before being consumed.

Feed-water heaters are also used, by which it appears a considerable saving in fuel is effected. The covering of the boiler and steam-pipes has also had much consideration, various non-conducting compositions being used; one of those recently tried is slag wool or silicate cotton, partly made from blast-furnace slag; it is applied either as a composition or in slabs curved to suit the surface.

Figs. 39A and 39B illustrate the most modern type of marine boilers for compound engines, as supplied to the S.S. *Parisian*, built by R. Napier & Sons, Glasgow, for the "Allan Line" of ocean steamers.

There are four boilers, each 15 feet in diameter, and carrying a working pressure of 75 lbs. per square inch, a hydraulic test having been applied, as is usual in such cases to double the working pressure, viz. 150 lbs. per square inch. The shell plates are treble rivetted in the longitudinal seams, and double rivetted in the circumferential seams. The furnaces are double butt strapped (see A, A in Fig. 39A on opposite page), and welded for a length of 10 inches at each end. The stays B, B are $2\frac{3}{8}''$ diameter, and are spaced $14\frac{7}{8}''$ apart. The tubes are $3\frac{1}{2}''$ diameter and 7 feet long, arranged vertically one over the other as shown in the figure. The total heating surface of the four boilers is 15,176 square feet, and the total grate surface is 540 square feet.

It will be seen from the dimensions on Fig. 39B that the thickness of the plates, which are of iron, vary, the thickest part of the shell being $1\frac{1}{8}''$, and the end plates from $\frac{5}{8}''$ at the tubes to $\frac{13}{16}''$ above these and where the stay rods are affixed.

These boilers supply steam to three-cylinder compound inverted engines working up to 6000 indicated horse-power, which are illustrated and described under Marine Engines.

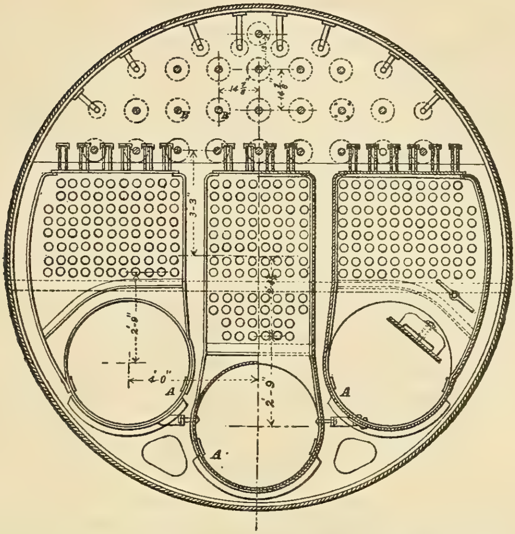


Fig. 39A.—Vertical Section of one of the Boilers of the S.S. *Parisian.*

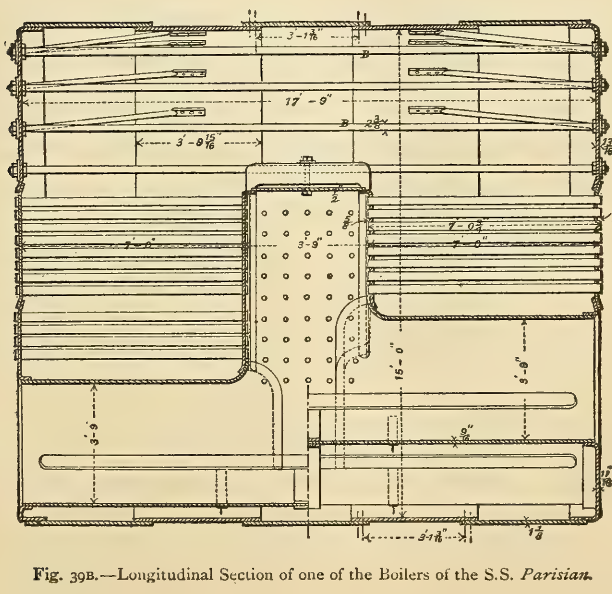


Fig. 39B.—Longitudinal Section of one of the Boilers of the S.S. *Parisian.*

THICKNESS OF PLATES, &c., FOR COAL BOXES.

Thickness of Side Plates,	$\frac{1}{8}$	inch.
Do. Bottom,	$\frac{3}{16}$	"
Do. Corner Angle-iron,	$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$	"
Do. Stay Angle-iron,	$2 \times 2 \times \frac{5}{16}$	"

Stayed every 3 feet apart.

For Coal Stowage allow 46 cubic feet per ton.

PRIMING.

Impurities in the water used is no doubt the chief cause of priming, and the evil is much increased by the want of proper circulation. We are apt to crush into small space a number of tubes, without ever considering how the water is to circulate around them. A continual ebullition goes on in all directions, the globules of steam are hurried through and between the water spaces in their passage upwards, and the water is allowed to fill up the cavity as best it can. A simple experiment on a kitchen fire will clearly point out how this frothing of impure water occurs. Take a vessel partially filled with pure water, place it on the fire, and the water will boil without flowing over; but fill the vessel half full of potatoes, with just sufficient water to cover them, when the water has boiled for some time a slight scum will be raised, and the water having thus become impure from matter extracted, will eventually overflow. This process is greatly accelerated by the small water spaces between the potatoes, the water having little or no circulation downwards. The tubes in a boiler fill up the water space in a similar way, and when the globules of steam are shooting in all directions there is no time for the water to circulate freely. It is a good plan to confine the great ebullition to those parts where the steam is more rapidly raised, by simply fitting circulating plates between the tubes and the side of the boiler and other parts, thus the space left between the circulating plates would be comparatively free from ebullition, and the surface water in the boiler would flow down and circulate upwards amongst the tubes. Were such plates fitted loosely over the furnace crowns, allowing the steam to escape freely at the top, the ebullition would be very great, the water circulating rapidly between the plates and the furnaces would tend in a great measure to prevent scale forming. The part mostly affected by the want of good circulation is the bottom of the tube-plate at

the back of the boiler, and the great heat at this part soon cracks the plate, if the scale that rapidly forms is not frequently removed. Of course, where water from a surface-condenser is used, little or no deposit is formed over the heating surfaces; but even with surface-condenser water, it is found necessary to allow a slight film of deposit to form, otherwise the corrosion that rapidly sets in would corrode the plates very quickly. As we cannot prevent the water frothing up when it is taken into the boiler in an impure state, we must simply consider the best means to prevent the water priming over into the cylinders. With a good height of steam-chest, and with the steam taken from the highest point, the bubbles of water will be broken up before reaching the top of the inside steam-pipe in the boiler, and when a slotted pipe is carried along the top of the boiler, perforated with a number of slits $\frac{3}{16}$ inch wide, should the globules of steam and water reach that height, as they cannot pass through the slits, they are broken up, liberating the steam, which finds its way through the slits into the pipe, while the water contained in the spheres falls down amongst the water in the boiler, with the additional advantage that the steam is taken away directly from over the surfaces where it is generated. However, when no priming takes place, a certain amount of water will be carried along with the steam; and when the steam-pipe is at one point, the atoms are all converging to that point, and the mere mechanical friction of the atoms of steam rubbing against one another tends to carry water through the steam-pipe into the cylinders, therefore the steam should be partially dried by an apparatus we will now explain.

TREATMENT OF STEAM FROM THE BOILER TO THE CYLINDER.

Steam generated from ordinary boilers is far from being a pure gas, properly speaking, it is quite dry and invisible. The vapour blowing off from the safety-valve shows a transparent ring near the orifice of the valve; this ring, however, soon widens, and mixing with the cold atmosphere, takes the form of a misty vapour, highly charged with watery particles; this vapour is soon dispelled, and

nothing but pure water falls to the ground in a gentle shower. Thus, wherever the steam comes in contact with cold surfaces in its passage to the cylinder, condensation takes place, and it is robbed of an amount of heat, and consequently pressure, thus wasting much valuable fuel.

The saturation of steam with watery particles, however, is not entirely due to condensation, as there are various other causes at work; for instance, when the steam-room in a boiler is not of sufficient height above the water in the boiler, the violent ebullition that goes on has a tendency to surcharge the steam with water. Again, if the steam is taken away from one end of the boiler, instead of from immediately over the parts where it is generated, the same result takes place, the atoms rubbing, too, against one another, in flowing towards one point, has a great tendency to charge the steam with water. Violent priming, whether from the want of circulation of the water in the boiler, owing to defective construction, or by a sudden change of water injected into the boiler, surcharges steam with water to an aggravated degree. When the boilers, steam-pipes, and cylinders are not properly clothed, condensation takes place, and watery particles will be mixed with the steam to a large extent, thus reducing its pressure.

Many schemes have been devised to superheat the steam in marine boilers by the waste heat in the smoke-box, or uptake, with the view of delivering it into the cylinder in a dry state. Many of these superheaters have been fitted to boilers defective in construction. Some authorities are of opinion that the best place for drying the steam is in the boiler itself, drawing it from high steam-chests and uptakes, thus the steam is taken away at a greater height from the level of the water in the boiler, while the heated gases from the tubes have time to act on the lofty uptake contained in the steam-chest, and drying the steam sufficiently for all practical purposes. In many cases it is not convenient to form lofty steam-chests, and then other means must be adopted for drying the steam, separate vessels, termed superheaters, being used for that purpose. The steam dried by such contrivances generally receives 80° of superheat above the temperature of the steam in the boiler, this is considered, with fine lubricants, a good working temperature, that is to say, steam of 60 lbs. pressure has 295° Fahr., thus the total temperature will be $295° + 80° = 375°$ Fahr.; but it should be borne in mind that the best oil or grease must be used as the lubricant, other-

wise the dry steam hardens the oil, to the detriment of the piston and slide-valve rubbing surfaces.

Some engineers consider that when the steam is superheated, it should be mixed with the steam in the boiler; little advantage exists, however, in this arrangement, for it appears a very doubtful proceeding to heat up the steam, and then rob it of a portion of the heat by mixing it again with steam from the boiler. The main thing to be studied is to give the steam a sufficient degree of superheat, so that in its passage to the cylinder it may not be cooled down below the temperature existing in its primary state in the boiler; thus steam in a dry state is passing into the cylinders, whereas without some contrivance for drying the steam in the boiler, or in the superheater, an admixture of steam and water presses on the piston, tending to diminish the power and increase the consumption of fuel.

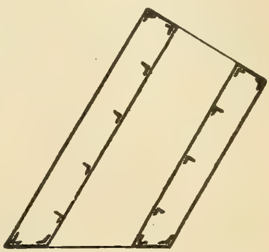


Fig. 40.—Cylindrical Superheater.

The various forms of superheaters may be classed just as are steam-boilers. The plain cylindrical form has an outer shell, containing a single large tube, the inner tube being stayed with rings of angle-iron; where double round boilers are used, firing fore and aft, the part fitting on to the boiler is bevelled, while the other end that joins on to the funnel is quite square; these superheaters, four in number, converge to one point, to which a single funnel is fitted, the bottom part of the funnel or the uptake being bevelled to suit; this form of superheater is simply effective, and easily constructed, while the scale can be readily cleaned out, and as it lies at a considerable angle the heat acts better on the surfaces.

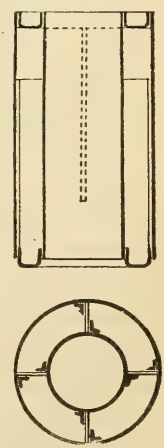


Fig. 41.—Cylindrical Superheater, with division plates.

Some superheaters of this class, however, are placed vertically, and it is an object with the designer to arrange passages so that the steam travels up and down within the superheater, time being required to dry the steam thoroughly. The passages are formed with plating rivetted vertically between the inner and outer shells, one of these plates is rivetted to the bottom and sides, another to the top and sides, and so on alternately; but at the top and bottom alternately the vertical

plates are not carried to the ends of the superheaters, an opening being left at these points; thus between the inner and outer shells cellular compartments are formed, the steam coming in at the bottom of one cell travels upwards, and then descends into another compartment, and so on according to the number of compartments, until it is finally carried away by the steam-pipe, the heated gases in this arrangement acting on the inside tube, the outside shell, and the lower end-plate, all of which are contained within the bottom part of the funnel.

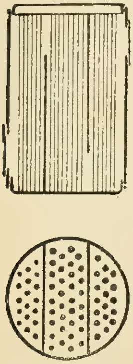


Fig. 42.—Tubular Superheater

Again, we have a vertical superheater of the cylindrical class, but instead of one large tube passing through it, a series of small tubes are securely rivetted to the end-plates, thus forming a multitubular superheater; again, time is required, so it is necessary to place division plates, rivetted to the sides and one end, having an opening at the other end, thus the steam being admitted at the top passes downwards, flowing all round the small tubes, and then upwards in the other compartments according to the number of division plates fitted, until it passes into the steam-pipe to the cylinder. Sometimes the multitubular type has the tubes lying horizontally, and division plates so disposed that the steam from the boiler enters at the bottom, passing through the small tubes, then returning, and finally passing through the top rows, thus the steam goes three times through, from the point where it enters the superheater, at the bottom, to that point at the top on the opposite side where it is taken away by the steam-pipe. In plan this arrangement has the tubes at the central part, the tube-plates being inclosed with a circular shell, and the tubes arranged in vertical rows. At the middle and sides there is space left so that the heated gases are not so much obstructed as when passing between the tubes; this makes a very effective arrangement, and may be reckoned a good example where time is required.

Many examples of tubular superheaters have been fitted directly on the tube-plate, some arrangements having the tubes merely a continuation of the tubes in the boiler, the pitch of the tubes in the superheater being identical. With this plan time is sacrificed and surface adopted; however, in some cases the tubes are laid the long way of the smoke-box, having boxes at each end, one end in communication with the steam-space in the boiler, and the other with that of

the steam-pipe to the cylinder. In some instances three boxes have been fitted to the superheaters, involving four tube-plates, the tubes running right and left from the central box; the steam from the boiler enters this centre compartment, passes right and left through the tubes, and is taken away with separate steam-pipes at each end. Sometimes the superheater forms part of the boiler; and for low boilers for marine purposes this plan has certain advantages, the tubes are arranged vertically, and are secured into tube-plates, running the entire length of the smoke-box, the lower tube-plate being a few inches above the tubes in the boiler, while the top tube-plate is placed a few inches from the top of the shell of the boiler. The steam from the boiler enters the superheater through a number of small apertures, these take a downward course; a division plate being fitted, the steam passing this plate ascends, and is taken away by the main steam-pipe; there are certain advantages connected with this arrangement, though the main one simply consists in doing away with a good deal of piping, as the steam from the boiler enters the superheater directly. The great desideratum to attend to in tubular superheaters is provision for cleansing them from the soot in the smoke passages, whether arranged internally or externally; some mode of access must also be provided to the steam space for cleansing away the scale that rapidly forms.

To employ a large flat surface, giving time to the steam to be thoroughly dried, is certainly the correct principle to be studied, when superheaters require to be placed in small space, though the complication entailed renders many arrangements of flat flue superheaters not at all to be commended in practice. Vertical flat flues, similar in construction to the overhead flue boiler with U-shaped end-pieces, and the plates flanged at the ends, for uniting them to the tube-plates, all of which are inclosed in a suitable casing, properly and securely stayed, with stay-bolts and ferrules, is an effective arrangement of the kind; the heated gases pass through the elongated tubes, while the steam is admitted at one end of the casing, and passes between the spaces left betwixt the flues, and is taken away by the steam-pipe placed on the opposite end of the casing. This plan of superheater is expensive in first cost, and complicated in its many parts in the event of repairing it and keeping the apparatus in thorough working order. In all cases where separate superheaters are used for marine purposes, a stop-valve and pipe must be fitted for each boiler, for shutting off, or allowing the steam free access to

the superheater. One stop-valve is fitted to the superheater for regulating the steam to the cylinders, while in connection with this stop-valve and pipe there is fitted a stop-valve on each boiler, having a pipe connected to the main steam-pipe, thus in the event of anything going wrong with the superheating apparatus, all the stop-valves connected to the superheater can be closed, and the steam taken from the boiler in the usual manner. This will show how much more preferable it is to form high steam-chests and uptakes; thus complication is reduced to the minimum, while at the same time the steam is effectively dried. Superheaters, in all cases when made separate vessels from the boiler, should be fitted with a safety-valve, of ample size; this is to prevent rupture, as, in case all the stop-valves are shut, a certain amount of moisture, or even steam, is in the superheater when the valves are closed, and this would generate a highly-explosive dry gas, or *steam proper*, were the safety-valve not relieving the superheater from the accumulating pressure. In the absence of steam in the superheating vessels, the injurious effect of the waste heat passing up the chimney acting upon the dry plates and small tubes need scarcely be pointed out.

In concluding this brief sketch of superheaters, that have all been practically tried more or less, it may be stated that for pressures of 60 lbs. per square inch in the boilers the simplest arrangement that is found in practice to suit all requirements is a circular shell fitted with an internal flue. The surface exposed, or total surface of the internal flues, in this system is 1·3 square foot for every nominal horse-power the engine is calculated for; but for low-pressure steam the surface is generally 1 square foot for every indicated horse-power the engine works to; or otherwise from 3 to 4 feet square per nominal horse-power is reckoned amply sufficient for the superheating surface, as usually arranged, for pressures varying from 20 lbs. to 30 lbs. steam in the boiler.

We will now consider the different points to be attended to in the arrangement for conveying the steam from the boiler to the cylinder. With the view of keeping the steam as free as possible from watery particles, as has already been discussed in the section on priming, a pipe is fixed to the interior of the boiler, perforated throughout its length with a number of holes, by which the steam is removed from over the parts where it is rapidly generated. This pipe should be fitted to all boilers, whether using superheaters or fitted with ordinary arrangements. The use of the separator has also been

explained, fitted to the steam-pipes, for retaining any moisture that is carried along with the steam, more especially steam that has not received a sufficient degree of superheat. The reader on turning back to page 46 will find the use of the separator fully explained. As the pipes are made of copper, which is a very good conductor of heat, it is necessary to clothe them with felt, and then cover them over with canvas, securely sewn together; the whole is then painted, to present a neat and smooth surface. The steam is still further treated in the cylinder by the use of a steam jacket encircling the cylinder in all parts where radiation takes place; even the ends and the covers of the cylinders are steam-jacketed, and are still further protected with felt, covered with "lagging," the technical term for narrow strips of wood that are firmly secured to rings of wood bolted to the cylinder, ribs being cast on for that purpose. Thus it becomes imperative that pipes and surfaces, exposed to external cold, should be thoroughly protected to prevent condensation or reduction of steam pressure. The boilers are likewise covered with felt and wood lagging, and sheet-lead overall, to prevent radiation

MANUFACTURE OF BOILERS.

In all branches of industry there are certain methods better adapted for carrying on work than others, and although one maker may adopt a very different method from another, they may be equally successful in turning out as good work, although the one may have expended more money than the other in doing so. Some, for instance, adopt modern improvements, and their plant is of modern make; the punching machine, for example, being superseded by the multiple drilling machine, and no one can doubt for a moment that drilling the holes for the rivets is done without straining the plates so much as with the multiple punching machine forcing through three holes at once, even although the drilling machine may be doing twenty holes at one time. The plating for boilers and other work is now done with mathematical exactness; the distance between the rivets for ordinary boilers, having ¾ inch rivets for securing the plates, is 2 inches between centre and centre, and from the edges 1 inch to the centres of the holes; consequently the plates should be ordered with even dimensions.

Some may say this cannot always be done, so as to give a boiler of a certain diameter. We will only remark that if the plates will not run evenly, an inch more or less does not affect the diameter very much, as likewise the length of the boiler is not generally so confined. The object of even dimensions is simply that when the plates arrive they are at once taken to the planing machine to have the edges planed, and then they are punched or drilled, as the case may be, the punching machine being provided with a travelling table, moved along by hand, the table having suitable stops, thus the machine templates or sets out the holes and punches at one and the same time. Now this could not be done if the plates were ordered of uneven dimensions. Those who have not adopted this plan for plating for all kinds of boilers cannot be aware of the great saving effected. We have known working drawings going into the workshop, and the boilers have been plated haphazard, stock plates being kept for that purpose. We may at once note this plan a complete barbarism. Plates should be ordered for each boiler separately, and properly marked both on the drawing and on the plates as delivered from the rolling mills, when they should be assorted, and the workman then knows where to lay his hand on No. 1 or No. 13 plate, as the case may be. By this rule being duly attended to much saving is effected. Indeed, a practised eye can at once detect when boilers are plated haphazard or regularly; and certainly it is not very pleasant to be told that this or that boiler has not the same appearance, owing to the irregularity of the plating as taken from stock; and great waste occurs when plates require to be cut down to suit a particular boiler.

For all difficult boilers block models should be made, and all the plates set out and marked, so that the workmen can see at a glance what the work consists of, the model giving a better idea than a drawing, and also standing more rough handling;—the drawing, in some cases, never being required in the workshop.

All the plates should be ordered for planing the edges; ¼ of an inch is the regular allowance for doing so, not that so much is required to be planed off, but at times the plates are not so square at the corners as can be desired. This method of planing the edges saves a great deal of chipping, and the joints are more easily caulked.

In plating the boiler care must be taken so that the flame does not act on the edges of the plates. All joints should be so laid that the flame passes over, and does not impinge against the end of the

plate, and all the outside edges should be placed downwards; thus the moisture freely runs down, and is not allowed to collect at these parts, preventing the rapid corrosion that would otherwise set in. The drawing should plainly show all the laps, to prevent the workmen from plating the boiler incorrectly. The plates exposed to the immediate action of the flame should be of the best description, more especially in the crowns of the furnaces, where they must run lengthways, and all the joints kept well out of the fire. Sometimes the furnaces are plated with butt joints and strips; this is a good plan for boilers intended to carry high-pressure steam. The end-plates of rounded boilers are usually attached and stayed to the shell with angle-iron at the corners, having three or more flat plate-stays, rivetted between two angle-irons at the ends and top, dividing the surface to be stayed equally. When the furnaces are inside of the boiler the angle-iron for joining the furnace with the end-plate is placed inside, at the furnace end, and outside of the flue-plates at the extreme end; but should the furnace be underneath the boiler the flues must be joined to the end-plates with angle-iron outside of the flues, or, in other words, inside of the shell. The water space underneath the boiler in this case will be more than in the former arrangement, with $2\frac{1}{2}$ inches breadth of angle-iron, not less than 5 inches between the flue-plates and the outside shell; and where two furnaces or flues are adopted, the same space should be between them: when stronger angle-iron is used the distance may be the same, but the angle-iron will require to be flattened or cut away at that point.

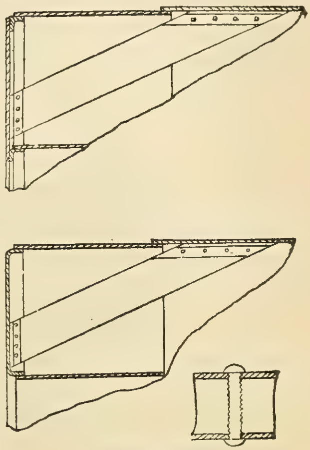


Fig. 43.—Plate-stays.

Sometimes boilers are ordered to be flanged in all the corner plates. When so specified, all the flanges should have a bold radius at the corners, not less than 2 inches: this makes a neat piece of work, and the strength of the boiler is materially increased. Water spaces, having flat sides, should be stayed together with $\frac{3}{4}$ inch screwed stays, tapped into both plates, and rivetted or fitted with nuts and washers outside, as occasion may require, the distance between

the stays being regulated by the steam pressure used. For strengthening the flues when they are of extra size sometimes angle-iron

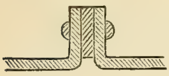


Fig. 44.—Flat Iron Flue Ring.

and manufactured hoops are introduced at the joints (see sketch on page 26). This plan answers well where deposits do not form rapidly; and although large flues, whether oval or circular, are not at all desirable, they can be strongly stayed with conical tubes, having the water inside of the tubes, which are most efficient stays, and give extra heating surface, and no boiler having large or flat flues should be without such a means of support. The tube-

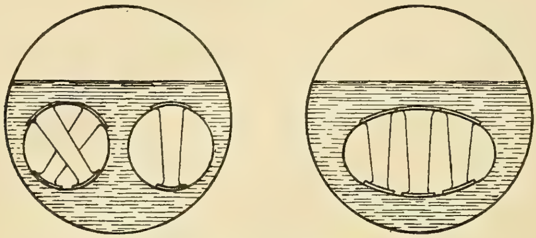


Fig. 45.—Conical Water Tube-stays.

stays are so made that the bottom parts with flanges can go through the top holes; thus they can be fitted to existing boilers cheaply. Such a system of staying must tend to decrease the number of

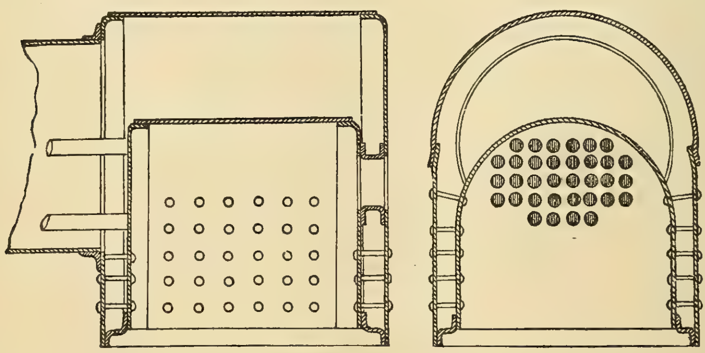


Fig. 46.—Flat Fire-box.

boiler explosions; but on no account should a boiler so fitted be tampered with. For staying the end-plates of round boilers T-irons are sometimes introduced, having long rods of round iron passing from end to end of the boiler, and jointed with pins and

cotters to the T-irons. With boilers having hemispherical ends it is quite evident that no stays are required. Flat fire-boxes (see page 88) for general purposes, and similar in construction to the locomotive type, should be well stayed; the inside fire-box can be made circular at the top, and for moderate pressure the flat sides are only stayed to the inside fire-box, with ¾ inch screwed stays, rivetted on the outside, the distance between the squares being 6½ inches for 50 lbs. per square inch, to 4¼ inches for 100 lbs. steam pressure per square inch. The plates are all flanged at the corners, but the fire-box is sometimes united to the outer casing, with angle-iron at the bottom. The short flange pipe, to form the furnace-door case, strongly stays the fire-box at that part.

As we consider that this subject closely affects the interests of steam users, we append the following from a report presented to the National Boiler Insurance Company:—"A large number of the boilers proposed for insurance are so weak in construction that some general remarks, based on the extensive experience of the construction and working of all kinds of steam boilers, will doubtless be found useful to many owners and makers. Of the numerous varieties none are more generally used than the Lancashire, or the cylindrical two-flued, and the Cornish one-flued boilers, and where these are well constructed, properly fitted up, and carefully attended to, their performance is generally satisfactory. There are various modifications of these forms, some of which are valuable. In designing such boilers excessive length, as compared with the diameter, should be avoided. Long boilers strain considerably, and frequently give great trouble by leakage at the rivetted seams. A fair proportion is when the length is about three-and-a-half times the diameter. The staying of the end-plates, and the attachment of the flue-tubes to the ends, should be so arranged that the tube may expand freely, unless there be some special arrangement in the form of the flue-tubes to attain the same object. Many boilers, otherwise well made, have given considerable trouble by leakage and fracture, owing to the severe strains of unequal expansion to which their rigid construction exposed them. In some of the boilers inspected the ends were so heavily stayed, and so rigid, that considerable leakage and occasional fracture at the ring seams of the lower part resulted. In others the staying was so slight that the ends were bulged outwards, and serious risk of explosion thus occurred. Flue-tubes should never be stayed to the shell, but be attached at the ends only. Many boilers

have given serious trouble through being thus stayed. The shell should be made quite circular, and the longitudinal seams, which should break joint, be so arranged that when the boiler is set all those below the water-line may be accessible for examination in the flues, and be clear of the brick seatings. Many makers now double-rivet these seams, thus materially increasing their strength, and, when the work is well performed, reducing liability to leakage. Flue-tubes are now constructed in various ways, some makers preferring to use thick plates not strengthened in any way, whilst others prefer comparatively thin plates, but flanging them at the ring seams, or by welding each ring of plates and connecting them by solid T-iron hoops, form a much stronger and more reliable flue-tube. The liability to leakage, fracture, and excessive expansion is thus much reduced, as the heat is more freely transmitted through the thin plates. The cross-tubes and water-pockets introduced by some makers in that part of the flue-tubes beyond the furnace bridge are of great value, chiefly from the manner in which they improve the efficiency of the heating surface by the diversion and breaking up of the current of gases, whilst they much increase the strength of the tubes to resist collapse. All large tubes exposed to high pressure should be strengthened by some of the means described. Where the tubes are formed with the ordinary lap-joints the longitudinal seams should break joint, as a tube thus made is much stronger than where those seams are in a line; and at the furnace end all longitudinal seams should be below the fire-grate level. The plan of forming tubes with the plates longitudinally in narrow strips is very objectionable, as the tubes cannot be made so circular, and the seams above the bars are injured by the action of the fire, whilst such tubes are much weaker than those made in the ordinary manner Multitubular boilers should, as far as practicable, be so constructed that every part of the interior may be accessible for cleaning and examination; and it would be a great improvement if those of portable and locomotive engines were so constructed that the tubes could be drawn out without difficulty, so as to allow occasional inspection of the internal surface of the plates. External flues are necessary to stationary cylindrical boilers of this class, otherwise the lower seams are strained, and become leaky through excessive unequal expansion of the boiler. Plain cylindrical externally fired boilers, with egg or saucer shaped ends, are preferred by some owners, chiefly on account of their simple form. Such boilers can

never work so safely as a properly constructed internally-fired boiler, as they are so liable to fracture at the seams over the furnaces, through the excessive alternate expansion and contraction to which they are exposed. The application of stout longitudinal stays would add materially to the safety of such boilers. A variety of cylindrical vertical boilers are used in various iron-works. These boilers are generally heated from the puddling or similar furnaces, the heat first entering the external flues, and passing thence by an internal descending flue-tube to the chimney. They are especially liable to starting and fracture of the rivetted seams opposite the furnace necks, owing to the intense heat at that point; and where the feed water deposits much sediment the solid plate is sometimes fractured. To avoid this liability the part referred to should be protected by a screen of brickwork, or the boiler set at a higher level; the brickwork may be so arranged as to spread the heat before it reaches the boiler. The bottoms of these boilers are frequently quite inaccessible for examination, and serious corrosion may go on unknown to those in charge. If the boilers were supported by brackets at the side, or by wrought-iron plate standards rivetted to the bottom, so that a thin wall of brickwork would suffice to form the flues, the condition of the plates could be occasionally ascertained without much difficulty.

"As the safety of boilers depends so much on the sufficiency and condition of their fittings, a few remarks thereon will be useful. It is well to have two safety-valves to each boiler, as a check upon each other; one of them should be a dead-weight valve, loaded externally, and the other a lever-weight valve, or a compound valve, which would allow the steam to escape, if the water were allowed to fall below the proper level. Safety-valves are frequently met with, the levers of which are of such length, that the usual working pressure for which the boiler was made would be much exceeded if the weight were fixed at the end of the lever. The weight should always be calculated and adjusted to hang at the end of the lever. All boilers should be provided with correct pressure-gauges for the guidance of the attendants. The glass-gauge is undoubtedly the best and most reliable water-gauge, and it is a good plan to attach two gauges to each boiler. Where floats are used there should be two, one of them fitted with an alarm whistle. Boilers with internal tubes should always be fitted with glass-gauges. Fusible plugs should be inserted in the furnace crowns of all internally-fired boilers. The feed regu-

lating valve, which may be constructed to act also as a back-pressure valve, should always be placed at the front end of the boiler, within the reach of the attendant, and where boilers work in connection, each should have a back-pressure valve attached. The feed water should be delivered a few inches below the surface of the water in the boiler, and above the level of the tube crowns, and in a horizontal direction, or by means of a horizontal perforated pipe. Where the feed water is delivered near or at the bottom of the boiler, it cools and contracts the lower plates, whilst those of the upper part are heated and expanded by the steam, frequently causing fracture at the ring seams at the lower part of the shell. The feed water should always be heated before it is forced into the boiler. The blow-out tap at the bottom of the boiler should be so placed that it may be examined at any time, so that any leakage occurring, it should be at once noted; valves should never be used, double-gland taps made altogether of brass are far preferable. Stout seatings with planed joint faces, suitable for each fitting, should be rivetted to the boiler. All manholes should be strengthened by a faced mouthpiece, rivetted to the boiler, so that the joint may be easily and well made, and leakage and corrosion avoided. Steam domes are unnecessary in stationary boilers; a perforated pipe placed in the upper part of the steam-space is quite as efficient to prevent priming, and the boiler is not weakened. Where domes are preferable, they should never be of large diameter, and the shell plates inside them should not be all cut away, that is to say, the hole should be strengthened with strips left in the plate. The setting of stationary boilers should always be intrusted to a man of experience. When boilers are about to be set, special care should be taken to thoroughly drain the ground, that no dampness may exist in the flues to cause corrosion of the plates. All the flues should be quite large enough to allow a man to pass through, so that every part may be accessible for repairs and examination. Midfeather seatings are very objectionable, and no boiler should be so set, except those of very small diameter, and in such cases, thick but narrow iron plates should be placed on the top of the brickwork to protect the boiler. Cylindrical boilers internally fired should be set on side walls, the boiler resting on fireclay blocks made for the purpose, and so shaped that when built in place the bottom of the side flues may be much lower than the point where the boiler rests on the blocks. If the blocks be properly fitted to the plates, that the bearing thereon may be

equalized, the total breadth of both side walls, where in contact with the plates, need not exceed 1 inch for every foot of diameter of the boiler. The top of the side flues should be level with the crown of the flue tube. All boilers should be roofed over to protect them from external moisture, otherwise the sides in contact with the flue brickwork will be weakened by corrosion. Where flues are properly arranged as described, no serious corrosion could exist in the seatings undetected by a skilled inspector. The laws for the prevention of smoke are now being enforced in many districts, but boiler-owners should be cautioned against too readily adopting any form of apparatus which may be pressed upon their notice, as many are unnecessarily complicated and expensive.

"It frequently happens that good boilers are injured and serious risk is incurred through neglect and carelessness. Where the feed water contains much sediment, and no cleaning apparatus is in use, frequent internal cleaning is indispensable, or the plates may become overheated and injured, whilst the efficiency of the boiler is reduced. The external flues are in many cases allowed to become almost choked before being cleaned, and the boiler plates so thickly coated with soot, that a wasteful consumption of fuel is the result. Some firms, on the other hand, clean their boilers thoroughly about once a month, and are thereby considerable gainers, as the efficiency of the heating surface is retained, whilst any defects are at once discovered and made good, which, if neglected, might entail expensive repairs, or even lead to serious disaster. When boilers are being restarted after stoppage, they should be heated very gradually, so as to avoid, as much as practicable, the severe strains of unequal expansion, and when at work the feed supply and the firing should be as steady and regular as possible. Frequent and extreme alterations of pressure, especially with high-pressure boilers, or irregularity of any kind, is most objectionable, and sometimes really dangerous."

We consider the foregoing remarks are well worthy the consideration of steam users, although we do not entirely agree with the writer in limiting the length of land-boilers to three and one half times the diameter; and we do not advocate too thin plates for flues, even though stayed with hoops, although the flues are thereby strengthened; but entirely agree with him that conical water tube-stays are invaluable for staying the flues, as deposit is not liable to form, as is the case with the hoops. We have known many instances where deposits have rapidly formed at the roots of the hoops,

thereby tending to injure the plates, by a thick coating, through which the heat cannot effectually act on the water, or, as it were, the water cannot keep the plates sufficiently cool and in proper working condition. This heating of the plates, whether from violent priming, or from carelessness in the attendant allowing the water to fall below the crowns of the furnaces, is the main cause why efficient steam-boilers at times explode. As already stated at page 32, steel plates are now being used for boilers, a reduction in thickness being thereby effected of about 20 per cent., and on the whole weight of the boiler about 10 per cent.

THE REGULATION OF STEAM BY THE SLIDE-VALVE,

AS APPLIED TO LAND, LOCOMOTIVE, AND MARINE ENGINES.

The reciprocating motion imparted to the piston of the steam-engine is caused by the steam acting alternately on the top and bottom of the piston; passages, or ports, as they are technically termed, being formed in the cylinder to admit the steam: these ports having a valve so arranged as to admit the steam above and below the piston alternately, with means of allowing it afterwards to escape into the atmosphere, or into the condenser, as the case may be. The valve in its original form was simply an oblong box of cast-iron, open on the front or face, having a flange all round, this face sliding on a corresponding part on the cylinder, both being accurately faced up, and made perfectly steam-tight, reciprocating motion being imparted to the valve by a simple arrangement similar to the crank and connecting-rod for the piston. This valve, from its peculiar sliding action, rubbing against a corresponding face on the cylinder, is termed the *slide-valve*. The older valve arrangements admitted the steam during the entire travel or stroke of the piston; there were three ports, two in the cylinder, one at the top and bottom to admit the steam into the cylinder, and a central one outside the cylinder for the exhaust or waste steam from it to escape into the atmosphere, or into the condenser, if so fitted. When the valve was at half stroke, the steam-ports were covered, the valve face for doing so being the exact width of the ports, that is to say, the steam ones. It is quite evident that at this position the piston must be either at the top or the bottom of the cylinder, and as the crank-pin for the piston rotates round a fixed point, similar to the crank centre for the

slide-valve, the former drives the shaft that gives motion to all the minor details, and as the slide-valve must be opened and shut as the crank-pin travels from one end of its path, in a line with the cylinder, to the other end, it is quite evident that the centre, or pin, for the slide-valve must be at right angles to that of the crank centre for the piston; or, more correctly writing, with the length of the eccentric rod as the radius, taken from the centre of the engine shaft, on a horizontal line, sweep the path of the centre of the eccentric, and the point intersected on the circle is the position of the eccentric centre when the crank-pin is at the commencement of the IN stroke. Or when the crank is moving towards the cylinder, at this position the centre will be above the horizontal line; but should the crank be moving on the OUT stroke, the centre of the eccentric will be below the centre line of the engine.

It is quite apparent from the foregoing that when the crank-pin has travelled one half of its stroke that the valve will be full open;

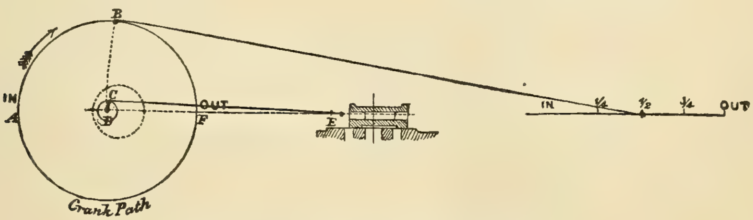


Fig. 47.—Original form of Valve without Lap.

A, Commencement of the IN stroke. B, The point on crank path at half stroke. C, Centre of eccentric at the commencement of the IN stroke. D, Centre of eccentric at half stroke of piston. C E, Length of the eccentric rod. F, Commencement of the OUT stroke.

and that when the crank-pin has travelled to the end of its path, or one half of the circle delineated by the crank centre, that the valve has returned, and covers the steam-ports exactly. At this position the crank-pin centre commences describing the other half of the circle or path, the piston is returning, and the slide-valve opens the steam-port for it to do so, at the same time the exhaust is becoming free, the steam which has acted on one side of the piston is escaping into the atmosphere as for non-condensing engines, or into the condenser, as with the low-pressure type; thus the steam acts alternately on the top and the bottom of the piston. It will be observed that the full pressure of the steam from the boiler was admitted into the cylinder the entire length of the stroke of the piston; this was wasteful, so it became expedient to admit the steam

for only a portion of the travel of the piston, or, in modern phraseology, "cutting off" the supply, the "cut off" being one fourth, one half, and so on, as might be determined on, the remainder of the stroke of the piston being actuated by the expansive force of the steam in the cylinder. So it was found that by adding a little more width to the slide-face, keeping the opening in ports by valve the same area, and making a new eccentric to suit the required amount of cut off, that the economical duty of an engine was greatly improved. This addition to the face of the slide-valve is termed the *lap* of the valve, or outside cover. Again, in high-speed engines it is found advisable to give the valve an amount of *lead* or opening before the piston reaches the end of the stroke; this is required to check the piston at the termination of each stroke by cushioning the moving mass gradually; thus the piston is brought to a momentary stand-still by the steam acting upon it directly from the boiler. It will thus be obvious that a piston of great weight and high velocity will require more lead or opening by valve than a piston of less weight, travelling at the same velocity; or, on the other hand, a much less piston, having a greater speed, may require the same lead as the heavy piston moving slowly. Were very little lead adopted in such cases, the moving mass being suddenly stopped at the termination of each stroke, a succession of blows would be imparted that eventually would damage the machine, and the lead is simply introduced to prevent this occurring, and to secure the earliest possible admission of steam, so as to obtain a large port area early in the stroke. The inside edge of the valve face should just cover or be in a line with the port, so that the exhaust is open at the commencement of each stroke a linear distance equalling the extent of the outside lap plus the lead; by this means the opposite end of the cylinder, or rather the piston, is relieved from the steam pressure, and the condensation fully established before the steam is admitted into the other end of the cylinder.

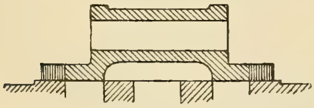


Fig. 48.—Valve with Lap. Vertical lines show the outside lap.

In proportioning the slide-valve of the steam-engine, the lead of the valve must be duly considered, a little more opening of port by valve greatly affecting the lap or outside cover, as likewise the length of the eccentric rod must be taken into account; as a rule, with a proper length of eccentric rod of not less than six times the throw of the eccentric, the versed sine of the chord contained by

the arc, or travel of the eccentric centre, equals the opening of valve minus one half of the lead. This may be taken in all cases to be practically correct when the valve is worked by direct means from the eccentric, but when levers and rocking-shafts are interposed between the eccentric and the valve, the versed sine will be more or less, as the case may be; thus supposing the eccentric rod lever is longer than the one on the rocking-shaft for the valve, the versed sine must be greater than for a direct motion, and *vice versa;* but in all cases the throw of the eccentric, or the circle described by the eccentric centre or pin, the lap of the valve, &c., must be found in the first place to suit the cut off in the cylinder, as for direct motion, and the levers proportioned accordingly.

Sometimes the valves for land-engines are made double-ported; this class of valve is simply adopted to reduce the "throw" of the eccentric, and secure rapid admission and cut off for the steam; thus with ports of the same length as for single-ported arrangements, we can, by having double or more ports, increase the area for the entrance and exit of the steam,—a matter of importance when a high rate of piston-speed is adopted.

When the valve is made large, it is necessary to relieve it from the steam-pressure that tends to force it against the cylinder face. There are a variety of plans for doing so: some engineers introduce a piston working in a short cylinder, placed in the valve-casing cover, connecting the piston to the valve by means of a vibrating link; by this plan it is lifted as it were off the face, thereby reducing the friction, as the valve is partly suspended, and consequently more easily moved. Others have introduced a flexible plate, connecting it to the valve in like manner, the spring of the plate acting in a similar way as the piston arrangement; both are acted on by the steam in the valve-casing, pulling the valve from the face, of course, according to the amount of area exposed. However, such arrangements are not to be relied on, and the end in view is attained by simpler contrivances. The usual method, now in extensive use, is by recessing two rings in the valve-casing cover, and pressing them against a planed face, on the back of the slide-valve, by a number of set screws, placed around, central with the recess; these set bolts press against a ring of iron in the first place, then a plaited gasket is interposed between this ring and the brass ring, which presses on the back of the slide-valve, thus making the area covered by the ring perfectly free from steam; the valve is by this means

relieved of much of the steam-pressure. A small pipe is introduced through the valve-casing cover, in connection with the eduction-pipe on the cylinder, thus any slight leakage of steam between the ring in the recess and the valve is taken over into the condenser when so fitted.

Other engineers have constructed the valve as a hollow frame, having merely sides; the back in this arrangement being fitted with a narrow piston-ring edge, having springs to keep the valve to the face on the cylinder, and also to press the piston-ring against the back of the valve-casing or the cover. This is certainly a refinement, and so long as the rubbing surfaces remain steam-tight, the plan is to be commended, as it is impossible such a valve, under any circumstances, can have any more back-pressure than merely the rubbing surface that is not covered by the piston-ring; but in the event of leakage between the rubbing surfaces, the plan is not at all to be desired, as the vacuum would be impaired, and great waste of steam occur. Therefore, when it can be conveniently applied, the plain ring system appears best, screwing the ring against the back of the valve, as such a plan can be adjusted at any time without breaking a joint, the set bolts being simply screwed into tapped holes in the valve-casing cover; it must be borne in mind, however, that the valve-gear must be proportioned to meet the full pressure on the valve, as at times the best arrangements will get out of order. When cast-iron surfaces are adopted, one-sixth of the total pressure on the valve may be taken for calculating the strength of the valve-rod and adjuncts, that is to say, if the faces are in good working order, and the lubrication properly attended to.

The position of the valve next claims attention. In all cases where practicable, it should be placed on its edge, so as to drain or run off moisture or water that may collect when the engine is not working, a small valve being fitted to the casing for running it off; thus the faces are kept as dry as possible, preventing the corrosion that would otherwise set in.

The reciprocating motion imparted to the valve is usually obtained by means of a simple eccentric, although cam arrangements at times find favour. The eccentric wheel or sheave has both a rotatory and reciprocating motion, its action is somewhat the same as a pin revolving around a fixed centre, such as the main crank-pin of the steam-engine; in fact, a plain crank and pin is often used instead of an eccentric; but when the line of eccentric or valve-rod cuts across

the engine-shaft, it becomes imperative to use an eccentric sheave, over which is placed a loose strap, to which is attached the eccentric rod; thus the eccentric sheave revolves inside of the strap, and the former being firmly attached to the main engine-shaft, communicates reciprocating motion to the valve and its adjuncts; the jointed end of the valve having suitable guides, so that the valve-rod moves in a straight line. To set out the eccentric, we will suppose the diameter of the engine-shaft is given, and consequently its centre, which we will term A; draw a straight line through the centre of circle delineating the engine-shaft, and on this line set off A B; this we will name the crank of the eccentric, the point B denoting the centre from which the eccentric sheave is described; the distance from A to B equals the outside cover, or lap, plus the full opening of the port by valve; then set off a proper thickness of metal for the eccentric sheave, around the shaft, and from the point B describe a circle touching the periphery of the circumscribed thickness around the shaft, and the circle described is the full size of the eccentric sheave; thus the basis is given for constructing the eccentric motion.

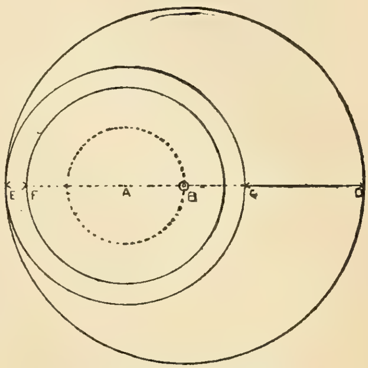


Fig. 49.—Eccentric Sheave.
A, Centre of engine-shaft. B, Centre of eccentric.
E F, Thickness of metal round shaft.
C D equals A B, multiplied by 2.

The eccentric is certainly not the best method of imparting motion to the slide-valve, as cams give a better cut off; but considering the great number of revolutions per minute many engine-shafts revolve at, it is the only motion that gives satisfaction, being regular and easy; whereas with high speeds the cams impart a succession of blows that would soon shatter the machine, and the noise would become intolerable. However, some steam-engines of the fire-engine class have neither eccentric nor cam motion, but simply an arm keyed on the piston-rod, having an oblong eye, working on a twisted flat bar of iron, thus imparting motion to the slide-valve; an arm is fixed on the end of the twisted bar for taking the valve-spindle, a short link being interposed between, with the necessary pins, guides, &c.

Having now considered some of the leading features demanding

thought in designing the slide-valve gear, attention must be drawn to the beautiful link-motion, as first applied to the locomotive, in its general application to land-engines, more especially to that

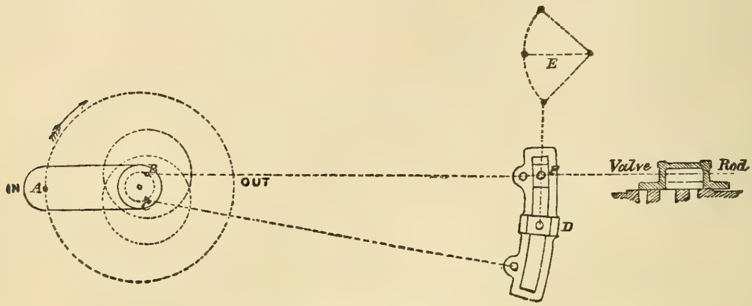


Fig. 50.—Link-motion.

A. Centre of crank-pin at the commencement of the IN stroke. B, Centre of forward eccentric. C, Centre of backward eccentric. D, Centre of suspension in link. E, Lifting arm. F, Slide-rod block.

class of engine requiring skilled men as drivers, or those technically termed engine-tenters. In days long gone past we have often handled colliery winding-engines, and it required a great amount of patience and skill to do it properly; but now it is done in an easy and satisfactory manner by the double eccentrics and link-motion, so that with an attentive man there is no fear of drawing the cage, with probably a living load, over the pulleys on the pit-head frame, as he can reverse or stop the engine with a single movement. Indeed, the numerous small engines handled in this manner every day lifting heavy weights quickly and under perfect control, lead many inquirers to consider that the double eccentrics and link-motion is the greatest improvement yet contrived in the mechanism for actuating the slide-valve.

There has always been an amount of mystery in explaining the action of the double eccentrics and link, while all allow that the common eccentric, or crank movement, is very easily comprehended. The latter is set to give a movement of the main crank of the engine in the particular way required; the eccentric centre being fixed, the crank-pin could by no means travel in the contrary direction *per se*, but by placing a twin-eccentric on the engine-shaft alongside of the other one, with the centre directly opposite, in relation to the main crank, the backward movement is obtained; then by connecting the extreme ends of the eccentric rods to a slotted link, so that this link can be moved up or down at pleasure, bringing the forward

or backward eccentric rod in a line with the valve-spindle, we have the power of moving the crank IN or OUT, as while one eccentric is in gear the other is simply doing nothing; they have joined hands, and are ready at a moment's notice for either going forwards or backwards, or by lifting the rods, and placing the link at midway between the centre of the eccentric rods, on a line with the valve-spindle; thus no motion is imparted to the valve, or but a trifle, and in this position the steam is shut off from the cylinder. In fact, the motion of the one eccentric is identically opposed to that of the other, and they can only move in contrary directions to open the ports as required; and being linked together, it is impossible that the one can do the duty of the other, or that both combined can ever fail in making the main crank of the engine travel in the direction required. When the link is down, the top eccentric may be named the driver (as in the locomotive) for the forward motion; but when the link is raised, the bottom eccentric rod becomes the driver, while the top rod simply moves to and fro along with the link which oscillates on the pin and block on the centre line of the valve-rod, reciprocating motion being imparted to the valve by the forward or backward eccentric, as the case may be. The radius of the link is found by placing the valve and adjuncts at half stroke, and the distance from the centre of the pin, for taking the valve-block, to the centre of the crank-shaft is the radius of the link, all the other dimensions or lengths being calculated accordingly; the point of suspension of the link is generally on this arc, described by the radius of the link, placed midway between the eccentric-rod ends, the distance between the eccentric-rod ends being usually three times the throw of the eccentric. When the link is drawn half up, the lifting arm being level, the suspending link should be nearly vertical, so as to equalize the motion; there are various methods of holding the link in position, which will be treated in detail further on.

The slide-valves for compound engines are so arranged, that two valves, fitted to one casing, is sufficient, one at the top and another at the bottom of the high-pressure cylinder, the port at the top and bottom admits the steam into the high-pressure cylinder, the next port is in communication with the passages for the low-pressure cylinder, while the third, or middle ports, are in communication with the condenser; thus there are three ports at the top, and the same number for the bottom, of the high-pressure cylinder.

The cylinders are arranged side by side on the centre line of the engine; the steam, after doing duty on the top of the small or high-pressure piston, expands to the bottom of the low-pressure piston, and then passes into the condenser; steam is also admitted to the under side of the small piston, from there to the top of the large piston, and then into the condenser; two long ports or passages are cast in the low-pressure cylinder, and there is a belt cast around the high-pressure cylinder, fitted with a pipe leading to the condenser. Such an arrangement, designed by the author, was fitted to a pair of engines for driving the machinery at the Royal Gun Factory, Woolwich. The valve gear was simply a crank-pin fitted to a cast-iron disc-plate; on the pin was secured a three-cornered cam, described from the centre of the disc-plate, one cross shaft driven by bevel wheels and shaft off the crank shaft, suited for both engines. This class of engine requires no cover on the valves, consequently the length from the centre of the disc-plate to the pin or centre of the cam is exactly the width of the exhaust-port into the low-pressure cylinder. This cam-motion opens the ports quickly, while the valve hangs, as it were, at the top and bottom of the stroke. With coupled engines the cams are of course set at right angles to each other, and as the weight of the valves is considerable, they are balanced with a weight, having a lever and links connected to the valve-spindle. There was no hand-gear, as factory-engines rarely require to be moved by hand, more especially when set at right angles to each other.

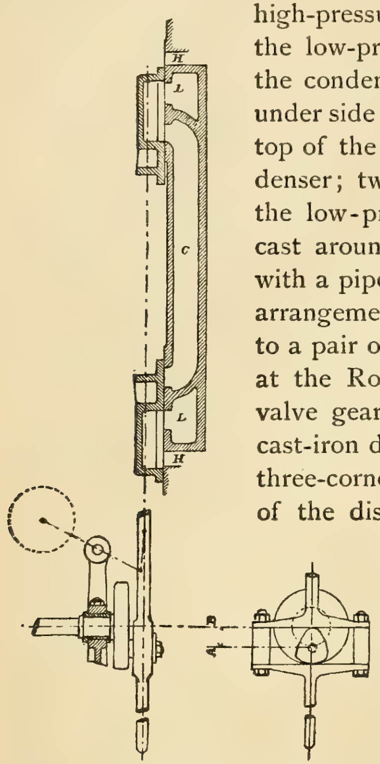


Fig. 51.—Valves for High and Low Pressure Combined Engines.

A B, Throw of the cam. C, Passage to condenser. H, High-pressure ports. L, Low-pressure ports.

The slide-valve for the locomotive-engine differs very little from land-engines; but certainly the locomotive type has arrived at a higher state of perfection than what is usually seen in engines for ordinary work. The various schemes for working the slide-valve of the locomotive,—and many arrangements have been tried,—have

resulted, at this date, in the universal application of the link-motion, with double eccentrics, as first practically introduced by the Stephensons.

However, there are a variety of link-motions; with some the links are curved, while others have them quite straight. Referring to those most in use, namely, those with the curved link, attention must be drawn to the various plans adopted for connecting the eccentric rods to the link. Some arrangements have lugs forged on

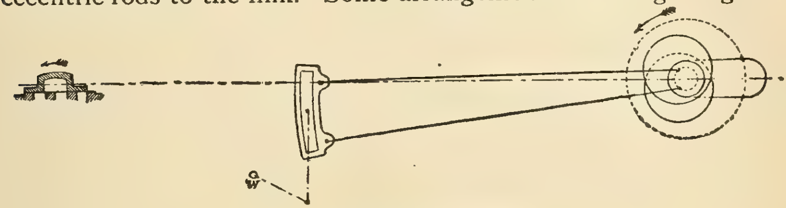


Fig. 52.—Locomotive Link-motion.
w, Weigh-shaft.

the link, within, and others without, the centre line of the link for connecting the eccentric rods (Fig. 52); other arrangements have no lugs whatever, but merely a plain link, having the eccentric rods connected to the ends, on the radius line of the link (Fig. 53), this plan necessitating the eccentrics to have a greater throw than in either of the two former arrangements. Some links are constructed of two side plates, with distance pieces, the eccentric rods being placed between them; while in other arrangements the link is a solid bar of iron,

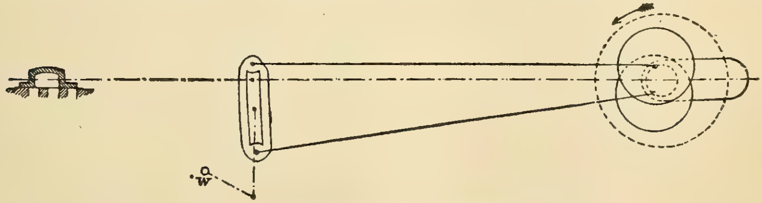


Fig. 53.—Locomotive Link-motion.
w, Weigh-shaft.

with the eccentric rods at the top and bottom on the centre line of arc, described by the link. Then, again, the mode of lifting and suspending the link is by a lever and rod, the point of suspension on the link is on the arc described by the radius line, and placed half way between the centres of the pins for the eccentric rods; thus the link and eccentric rods are raised or lowered simultaneously. With other arrangements the link is not lifted, but merely oscillates to and fro

on a pin and suspending-rod, having a fixed centre at end on which the arm oscillates; this arrangement is complicated, as a movable

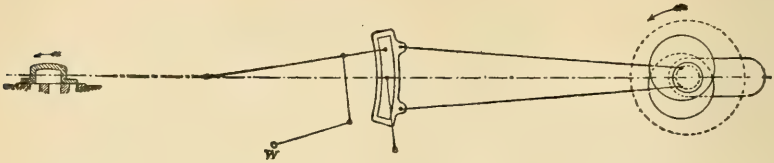


Fig. 54.—Locomotive Link-motion.
W, Weigh-shaft.

rod must be interposed between the link and the valve-rod, with the necessary lifting lever and rod to raise or lower it as required to suit the forward and backward motion of the engine (Fig. 54).

Again, some link-motions differ entirely from the foregoing, the link oscillating on centres, on the guide-bar for the valve-rod, sup-

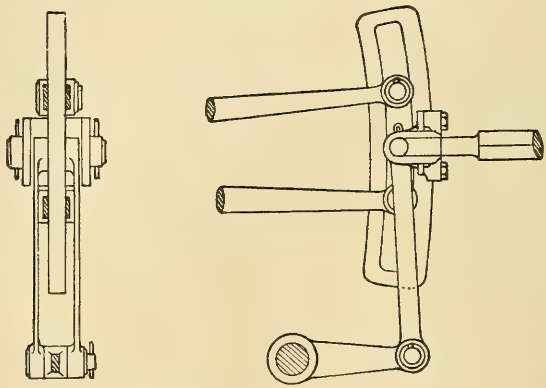


Fig. 55.—Locomotive Link.

ported close to the link, while the eccentric rods are connected to the sliding-block; this arrangement admits of the boiler being placed lower down, as the link requires less head room; the link-block is of increased length to insure steadiness; and as the reversing lever supports only the eccentric rods and link-block, the slide-valves are more easily handled, although all can be so arranged with counter-weights to ease the labour in reversing (Fig. 55).

The great value of the link-motion not only consists in enabling us to control the movements of the engine, but it is likewise admirably adapted for cutting off the steam at any portion of the piston's stroke, thus working expansively without the aid of an additional valve and mechanism, and also simplifying the

machine, for undoubtedly all motors, especially those travelling at such high speed as the locomotive-engine, should be as simple as possible.

The means adopted for keeping the link in position, to suit the grade of expansion that is required, is effected by placing a lifting arm on the weigh-shaft that crosses the engine, having a rod attached, passing along to the starting platform, to which is fitted a quadrant and reversing lever for taking the long rod, connected to the lifting arms, on the weigh-shaft. The reversing handle has a catch and quadrant having a number of notches cut on its periphery, so by pulling the reversing handle the link is raised; the catch is then released, and being fitted with a spring, instantly drops into any one of the notches, thus holding up the link. As the weight of the links and rods is considerable, they are balanced with a weight fitted to an arm on the weigh-shaft; thus the power required to move the links and rods is equalized very nearly.

Many well-designed link-motions, from imperfections in the mode of suspension, have failed to give all the requisites necessary for a perfect motion, a free admission and release of the steam being of the first importance. The lead or opening of the port by valve at the commencement of the stroke should be equal, or nearly so, for all grades of expansion, both for the forward and backward movement; this being the case, the release must follow as a matter of course. It is often necessary, when designing a new arrangement, to make a skeleton model, to practically test the best position for suspending the link, as the latter becomes very sensitive should this point not be duly attended to. However, by carefully laying out the valve-gear on paper, drawing it accurately to scale, testing by delineation the various positions, the proper point of suspension can be arrived at without the aid of the model. The point of suspension of the link itself is midway between the eccentric-rod ends, on the arc described by the radius line, or nearly so, and on which the suspension-rod should vibrate equally forward and backward. Some links are suspended from the bottom, on the pin, for the backgoing eccentric-rod; and instead of the valve-rod being guided as in the former examples, a long rod is jointed to the valve-spindle, and supported at the link end with a vertical oscillating arm, having a double joint and pin direct, passing through the long rod, the link-block working in a double joint on the end of the rod, the block moves slightly up and down, following the arc of the oscillating

arm, the pin for the arm being placed as near the link-block as convenient.

It will thus be seen that link-motions for the locomotive are of three classes. In the first the link moves, or is lifted vertically, carrying the eccentric rods along with it. In the second the link is stationary, having no vertical movement, but simply oscillating on the suspending rod, the valve-rod being lifted and depressed for the forward and backward movements. And thirdly, the link is likewise stationary, oscillating on pins placed on the valve-rod; the eccentric rods are connected to the sliding-block in the link, the rods and block being raised vertically, so as to suit the forward and backward movements. The latter plan appears the best motion, as the action of the valves is more correct, from the link being fixed at the centre, and the valve-rod guided in a straight line.

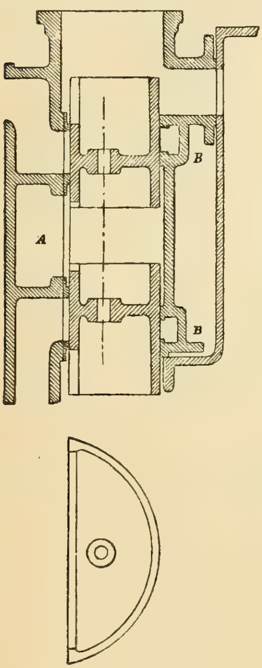


Fig. 56.—Long D-Valves.
A, Steam from boiler. B, Packing spaces.

For modern marine engines, although the long and short D slide-valves have almost become obsolete, they are at times still adopted, the sectional area resembling the letter D, hence the name given to this class of valve; with the long D, the valve is cast all in one piece, the steam-ports in the cylinder being as short as possible. The steam from the boiler, instead of passing into the valve-casing, as with ordinary arrangements, is admitted on the face of the valve, and the back or curve of the valve is made perfectly steam-tight by means of a plaited gasket, and packing pieces of metal inserted in the recesses at the top and bottom; the steam exhausting into the condenser at the top and bottom edges of the valve, the long D-valve, from its great size, in some instances exceeding 8 feet in length, was necessarily a heavy casting, so two short D-valves are generally adopted, held together by means of wrought-iron rods. The steam is admitted into the valve-casing through what, in ordinary engines, forms the exhaust-port in the cylinder, and passes all round the valve, which is made steam-tight, as before stated, with hemp packing. The cover

for the valve is suited for the under side of the top port and the upper side of the bottom port, while the exhaust takes place at the top and bottom edges of the steam-ports. The face on the cylinder is generally made of brass, rivetted to the cylinder, with brass pins screwed into the cast-iron. The valve-gear for paddle-wheel engines is generally fitted with a loose eccentric, revolving with the main shaft, having all the necessary stops on the eccentric and the shaft for the forward and backward movements, the eccentric rod end taking a lever on the weigh-shaft, fitted with the usual gab for throwing the valve out of gear, having a long lever handle on the weigh-shaft for working the valve by hand. As these valves are at times very stiff to move, provision is made for securing a rope to the end of the lever, so that a number of men may be employed to shift them. The weigh-shaft is fitted with a lever for the valve rod, and another for the back balance weight. This class of valve was generally used for the side-lever engine, and it is evidently desirable that it should be capable of being easily and quickly handled, as men pulling at a rope, perhaps when the vessel is pitching and rolling about in a heavy sea, is inconvenient and dangerous. A wheel and pinion, therefore, is sometimes introduced to secure greater ease in working the valve.

The slide-valve for oscillating engines is generally of the same type as is adopted for land engines, being fitted with a packing ring on the back of the valve to relieve it from much of the steam pressure. The valve mechanism being entirely different from any other class of engine, the eccentric is loose on the shaft, and fitted with all the necessary stops for the forward and backward movements. The eccentric rod is fitted with a gab at its end, working on a pin attached to an open curved link, made so as to suit the oscillation of the cylinder; a rod passing upwards is forged along with the link, having means of guiding it at the top with a bracket fitted to the head-stock or framing for the main-shaft, the link itself being guided at the bottom with suitable slides, fitted to the pillars for supporting the head-stock. This valve gear, in its simplest arrangement, has a plain handle, fitted with a rod for attachment to the quadrant, with a means of throwing the gab on the eccentric rod out of gear; thus the valve can be moved very quickly for small engines. The cylinder is usually fitted with two valves, but sometimes with only one; the double arrangement is introduced to balance the cylinder. The valve spindles have guide-bars forged

on at the top, fitted with sliding blocks. There is a weigh-shaft, working in suitable bearings, placed on the cylinder. This shaft sometimes curves round the cylinder, with a bearing for each end, but the general plan is to forge in one piece the levers for taking the valve rod and quadrant, introducing a long bearing between them, oscillating on a single journal fitted to the cylinder. Both ends of the levers for taking the quadrant and valve spindle are fitted with pins and loose sliding blocks. Where but one valve is fitted, the centre of the pin in the lever for the sector end is placed on the centre line of the engine. When the valve is at half stroke, the levers being at right angles to the centre line of the valve spindle, the distance from the centre of the pin to the centre line of the trunnion for the cylinder is the radius of the link or sector. Two valves are, however, generally adopted, necessitating the blocks for the sector being kept slightly apart; then the radius for the sector is measured from the centre of one of the pins to the centre of the trunnion. Thus it is evident that the arc of the sector must sweep the centres of both pins on the levers, however far distant from each other they may be placed.

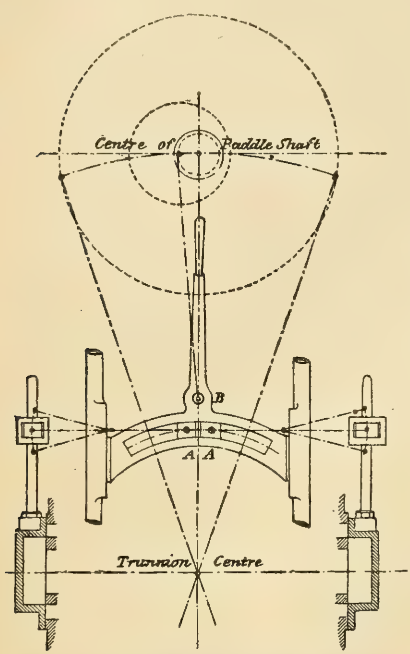


Fig. 57.—Valve Motion for Oscillating Engines.
A A, Sector slide blocks. B, Pin for the gab end of eccentric rod.

The hand-gear for small power is simply a lever, with link attachment to the sector, but for heavy engines a hand-wheel and pinion, working in a rack connected to the sector, is usually adopted; while other arrangements have double eccentrics and link motion, with suitable pin and block fitted to the sector, at a convenient place as near to the centre of the sector as practicable. The valve levers in connection with the quadrant being placed at the half travel of the valve, the vertical distance from the centre of the guide-block pin on the quadrant to the centre of the main shaft is the radius of

the reversing link. The forward and backward movement of the link is actuated by a starting-wheel working a worm-wheel and sector, the shaft for carrying the sector-wheel being fitted with levers and rods for connecting to it. Although the link motion and gear for the oscillating engine is somewhat complicated, the action of the double eccentrics and link is similar to the locomotive; each must be set identically the same in relation to the main crank of the engine; the only difference necessarily existing is the sector for communicating motion to the valves, and at the same time accommodating itself to the vibration of the cylinder.

For direct-acting horizontal marine engines the valve now generally adopted is of the multiple-ported type, having the ports double or in some cases in triplicate. This valve was introduced so that a large opening of port by valve could be obtained, with a moderate throw of eccentric, thus reducing the size of the eccentrics and gear into as small a compass as possible. The valve is usually placed on its edge, so that it is worked directly from the engine shaft by double eccentrics and the link motion. Some engineers place the valves on the top of the cylinder, working them with a system of wheel-gearing similar to the back motion of a turning lathe; the valve spindles are connected by suitable rods to a revolving crank shaft, then by a series of wheels driven off the main shaft of the engine, so by shifting the position of the two intermediate wheels the relative position for the forward and backward movement is obtained in relation to the main crank of the engine. This motion, somewhat modified, is considered by some authorities as perfect a motion for actuating the slide-valve as can be conceived, although the wheel-gearing is very objectionable, and certainly the link motion and double eccentrics is better calculated for modern marine engines. As the valves for large engines are of considerable size, and consequently the gearing heavy, and although only a portion of the dead weight of the eccentric rods, link, &c., has to be lifted, that, along with the friction, is considerable; and in all cases where matter is to be actuated by hand, time must be had, and consequently power, to do so,—it is therefore necessary to arrange proper mechanical appliances for the handling of the valve mechanism of the marine engine. The usual hand-wheel, with worm-wheel and sector-wheel, lifting levers and rods, is by far the best plan, as the link can be held up in any position, so as to work expansively if required; but this is rarely resorted to, as it is a much better arrange-

ment to provide a separate valve to work expansively, allowing the slide-valve to move always in full gear: thus the valve faces are worn evenly. Some makers have introduced a cylinder having a piston and rod so connected to the link that the reverse movement is actuated by steam pressure; and where marine engines, such as those in the Royal Navy, require an expeditious means of handling, this plan has a decided advantage in being able to reverse the engine, or manœuvre the screw propeller quickly, when the ship is in action.

There are a variety of arrangements for link motions applied to the slide-valves of marine engines, but the arc of the link is described the same way in all cases, no matter whether the link is slotted out, or simply solid; when the valve and adjuncts are at half stroke, from the centre of the crank shaft to the slide-valve block, or centre of the pin on which the link vibrates, is the length of the radius that describes the arc of the link. Some examples of valve-gear have two valve rods, with eccentric rods on the return principle, one of the valve rods being placed above and the other below the main shaft of the engine. The rods are guided on the condenser with a long sliding bar, having snugs forged on to take the rods. The lifting lever is

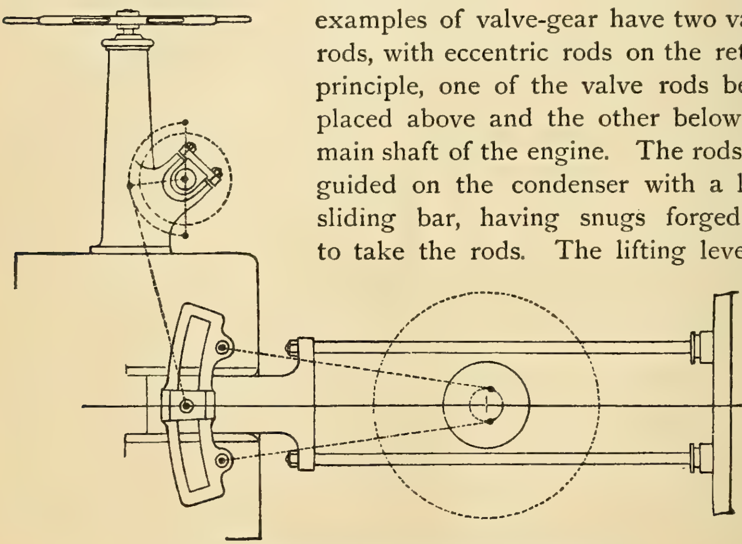


Fig. 58.—Link Motion and Starting Gear for Marine Engines.

placed on the top of the condenser, having a rod passing downwards, taking the reversing link at the centre and on the arc line; the lever shaft carrying a toothed sector, working into a worm-wheel placed vertically, having the starting handle or wheel horizontal. In this arrangement the reversing lever makes a half revolution, consequently this mode of suspending the link is not well calculated

to work in any other grade than full gear; but should it be desirable the lifting lever can be made longer, and so arranged as to travel merely a portion of the circle, keeping the lifting link nearly vertical throughout. Thus the suspension of the link in this manner is better calculated for working expansively; but it must be borne in mind that when the slide-valve works for any length of time in an intermediate position it is apt to wear a hollow on the cylinder face. Instead of the two rods for the slide-valve, as in the previous example, with the return eccentric rod system retained, one valve rod has been substituted, placed above the main shaft of the engine. The action cannot be so good as with two rods, owing to the eccentric rods working at a considerable angle, the proper position being in as nearly a straight line as possible with the valve rods. When so fitted for direct action the valve rod is guided with a suitable cross-head, placed at the side of the rod. This works in cast-iron guides, bolted to the valve-casing; the link is suspended similar to the

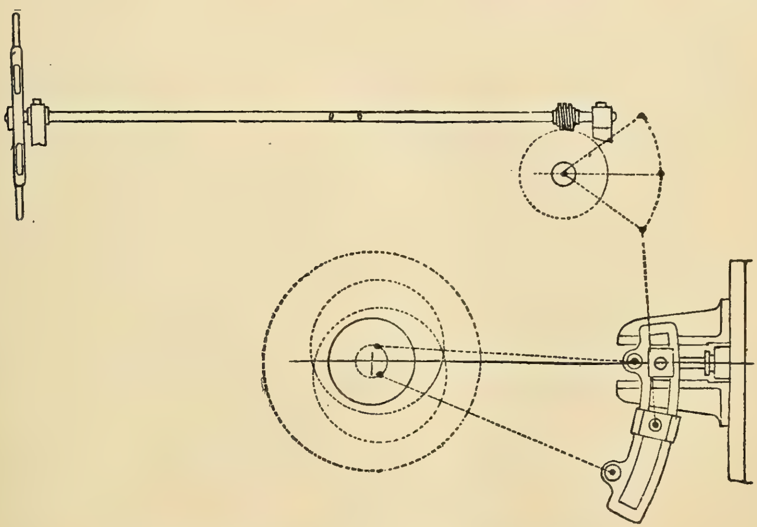


Fig. 59.—Link Motion and Starting Gear for Marine Engines.

locomotive arrangements, thus working expansively by the link. The plan may be adopted for small engines, but undoubtedly for large power there should be a separate valve for working expansively. The brackets for taking the reversing lever are placed on the main framing, the starting wheel is on its edge or at an inclination; the shaft for carrying it is supported at both ends, and is fitted with a

worm-wheel and pinion. This gear is very generally adopted, as the link is locked at any position without any other mechanism for holding it up. Some arrangements for direct action have the eccentric rods too short; where it is not convenient to get in a length of rod that is the radius of the link, at least six times the throw of the eccentric, indirect means are preferable for working the slide-valve; and certainly the return eccentric rod system, as before described, seems as good an arrangement for indirect motion as can be devised. It is essential that the suspending rod for the link should be made as long as convenient: this is a very necessary point to attend to when arranging link motions, as when the rod is too short the versed sine of the chord of the arc that it describes becomes very great, causing the link to have an up and down motion, which sensibly affects the working of the valves, more especially when the eccentric rods are short. Indeed, when such faults are both combined in one arrangement there is no truthful action of the valve whatever, and in all cases this can be avoided with proper attention. It is quite unnecessary to describe such malformations.

The modes adopted for guiding the lifting rod in a vertical manner must next be considered, and this apart from the starting-wheel, as its position varies very much, and is simply arranged in the best locality for handling the engines, which undoubtedly is on the same level as the stoke-hole, although some engineers place the starting gear on the top of the condenser, or about the same height as it, thus getting a good view of the machinery in motion. With bevel-wheels and cross shafts it is a very simple matter to place the starting gear in the most convenient situation; but all means should be as direct as circumstances will admit of. In guiding the lifting rod for the link in a vertical manner a simple kind of parallel motion is sometimes used. The lifting rod is suspended downwards, the bottom pin is fixed to the middle of a short link, the ends of the link taking an arm placed above and another below the lifting centre; one of these arms merely vibrates on a fixed pin, while the other or bottom one is keyed on the reversing shaft that passes across the engine. This shaft is likewise fitted with an arm for taking the reversing rod, passing along to some convenient part on the condenser. In this example the reversing rod is attached to a cross-head moving in suitable guides, the starting-wheel actuating a screw cut in its shaft, the cross-head having a female screw to correspond. It is quite essential that all link motions should be balanced with a

counter weight, keyed and fixed to an arm on the reversing shaft. Instead of parallel motion for keeping the lifting rod in a vertical line, a plain cast-iron guide is at times adopted, having a sliding block for taking the lifting pin, and the reversing levers, similar to

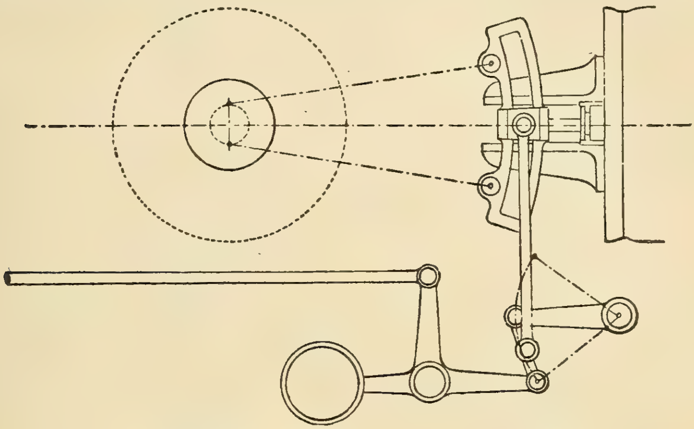


Fig. 60.—Link Motion and Starting Gear for Marine Engines.

the foregoing example, fitted with a short link for connecting the reversing arm and sliding block; the lifting rod being attached to the pin on block and main link, doing away with the top arm, as in the previous example. In some designs the link is not suspended for the forward movement, but simply rests on the slide block. When the link is full down, the lifting pin on the arm passing through a short slotted hole in the rod, the pin being free to move in the slot to suit the vibration of the link, there is neither upward nor downward movement in the link, as it is always resting on the slide-block for the forward movement, the pin in the elongated hole accommodating itself to the versed sine of the lifting rod. Another mode of lifting the link is by means of a screwed rod placed vertically (Fig. 61), having bevel-gear overhead in connection with the starting-wheel. On the screwed part of the vertical shaft at the bottom is fitted a nut, having two pins, for taking the short links that are fitted to the lifting arm, the lifting rod for the main link being jointed thereto; the pin is placed between the end and the centre of vibration of the lifting arm. The shaft for the lifting arm passes across the engine, having merely a plain lever and rod at the other end for actuating the main link.

A variety of other examples suited for the slotted link as well

as for the solid one could be given. Suffice it to say, however, that when solid links are adopted the eccentric rods are connected to

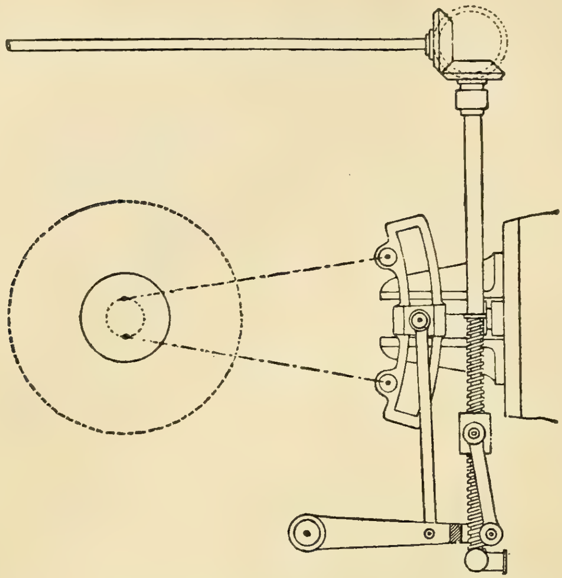


Fig. 61.—Link Motion and Starting Gear for Marine Engines.

the ends of the link, one of the pins taking the lifting rod being connected to the lifting arm with similar mechanism as for the slotted link. However, when the link is suspended from any other centre than the true one, at or near the centre of the link, the motion of the valve is not so correct as with the plans described above. For very small engines we would certainly adopt the usual starting gear as applied to the locomotive engine, having a plain lever handle fitted with a catch, and quadrant notched to suit a varying expansion; but of course this must only be used where the strength of one man is sufficient to work the valve-gearing.

From the brief sketch above given of some of the plans most in use for giving motion to the slide-valves of the marine engine, it will be seen that, where circumstances admit, the two former examples are the simplest motions, as having fewer working parts; and it must be borne in mind that simplicity in the machinery on board ship is the main thing to be studied.

In concluding this part of the subject attention must be drawn to a species of valve and gear for working expansively, termed the gridiron expansion-valve, of which there are two kinds; one being

quite flat, while the other is circular. The former is simply a flat plate, having a number of slots or openings, strengthened with ribs cast on the back; the valve is of brass, as likewise is the face it works upon. It is placed as near to the main slide-valve as possible. There is a considerable steam pressure on the flat type, and to obviate that

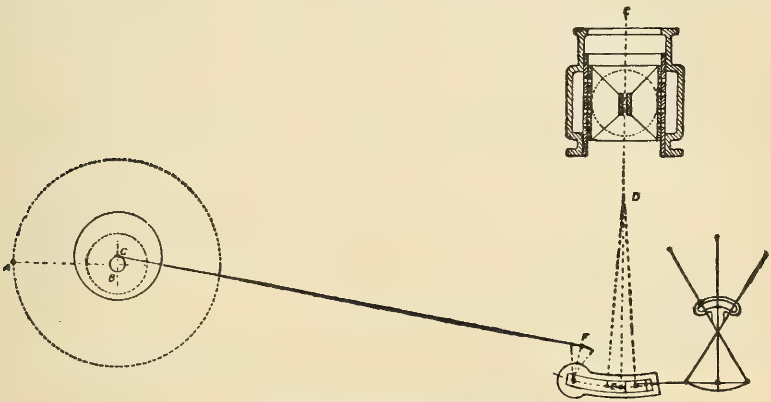


Fig. 62.—Expansion Valve Gear.

A B, Line of crank, C, Valve chest. D E, The radius of expansion link. F, Lever end for ditto. G, Centre of eccentric at the beginning of the stroke.

defect circular valves have been introduced, one species being in equilibrio, consisting simply of a series of rings and openings cast all in one piece, and having a central boss with ribs radiating from the centre. These ribs hold all the rings together, the openings being 1 inch broad for large valves; five of these openings have been adopted, giving ample area. This valve is accurately turned to fit a similar cylinder of brass, with openings to correspond, held together with vertical ties, cast all in one piece—the whole being encased in a cast-iron valve box, having an annular space all round. The steam from the boiler passes down through the hollow valve, and then round the annular space into the slide-valve chest on the cylinder. At the commencement of each stroke the ports are full open, and the valve gear is so arranged as to cut off up to a little more than one-half of the stroke; at least, practically speaking, this is attained (while the slide-valve for the engine is arranged to cut off at five-eighths of the stroke of the piston). The valve gear consists of an eccentric, having a throw of 2 inches, the eccentric rod taking a lever 4 inches in length. This lever vibrates on a short shaft, on which is fitted a slot link with a movable sliding block, to which is attached the con-

necting rod for the valve spindle. As the circular valve depends on its fit to make it steam-tight, it is evident that it should be arranged vertically, so that the wear may be as little as possible. To set out this valve-gear the line of the main crank is placed level, the crank pin being at the commencement of the IN stroke; the valve is set full open, and at a point on the valve spindle, with a certain radius to suit, describe an arc: this is the curve of the link. It is evident that when the sliding block in the link is moved to and fro along with the radius rod in connection with the valve spindle, the line of the crank being level, that no motion is imparted to the valve, or even when the crank is revolving the radius link can be drawn to the centre of vibration of the lever shaft; thus the valve always remains open when required, the lever and link simply vibrating to and fro. The motion of the lever is always constant, travelling in an arc due to the throw of the eccentric, while the pin and block working in the slotted link can be moved out at pleasure, giving a varying throw. Hence the valve can cut off the steam supply up to one-half of the stroke of the piston; but from the nature of the motion, the eccentric passing the dead centre of its throw, while the crank for the engine is gaining rapidly, the valve does not commence to open until the piston has travelled about five-eighths of its stroke, when the main slide-valve has come into action, and consequently no more steam can be admitted into the cylinder. Thus the expansion-valve gives a varying cut off from the valve-casing, while that of the main slide-valve admits a constant volume into the cylinder, developing the full power of the engine while so doing. The block and pin for the separate expansion-valve can be drawn back to the centre of vibration, leaving the passages in the expansion-valve always full open. This single eccentric and link motion for working an expansion-valve separately from the main slide-valve can be arranged for any class of valve, as likewise the locality of the valve in relation to the eccentric on the main shaft, the arrangement given being originally designed by the author for marine engines.

The geometry of the steam-engine next calls for attention, at least that portion of it which immediately bears on the subject of valve motions. This must be always carefully studied, in order to determine all the points requisite in arranging the slide-valve, the lap and lead of the valve to suit a given cut-off in the cylinder being of the first importance.

THE CONNECTING ROD AND CRANK.

The length of the connecting rod varies considerably, those of direct-acting marine engines being much shorter than in other arrangements. Taking an example, however, where the length equals five times the length of the crank from centre to centre; when the centre of the cross-head, where the connecting rod is attached, is placed at half stroke, from the centre of the engine shaft to the centre of the cross-head is the length of the connecting rod, delin-

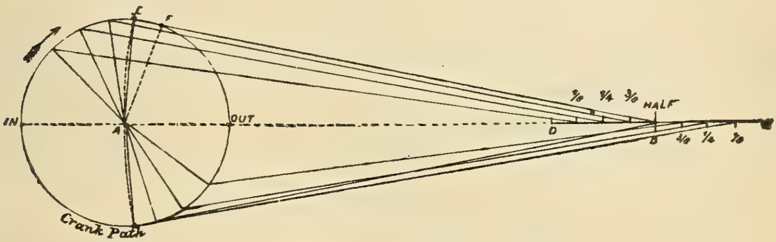


Fig. 63.—The Connecting Rod and Crank.

A, Centre of engine shaft. B, Half stroke of piston. C, Point on crank path at half stroke.
D E, Stroke of piston. F, Point on crank path at ⅝ths of the stroke.

eated as from A to B. With B A as the radius describe the arc A C, draw a straight line from the centre A to the point C on the crank path; this is the centre line of the crank at half stroke, the point C being the centre of the crank pin above or below the centre line of the engine. It will be seen that there is a great difference of the travel of the crank pin on its path for the IN and OUT strokes, the arc described for the IN stroke being greater than that for the OUT, as delineated from IN to C above the centre line, and from OUT to C below the centre line of the engine. There is no remedy for this variation; it is inherent in all crank motions, and varies as the length of the connecting rod. It therefore becomes imperative to find the point C to suit the length of the rod, as likewise to determine the point on the crank path for the particular part of the stroke of the piston that may be determined on for cutting off the steam. Thus supposing it is desirable to cut off at five-eighths of the stroke of the piston, the arc A C will be greater than for the half stroke, and *vice versa* when the point of cut-off is sooner than the half stroke. The particular point is easily found by taking the radius, and placing the point of the compasses on the first point

from B to E, then cut the crank path at F, the dotted line A F is the line of cut-off by crank when the piston has travelled five-eighths of its stroke. This angle is always the same, no matter whether the stroke or length of the crank is longer or shorter; that is to say, if the connecting rod bears the same proportion to the crank, namely, five to one.

THE CRANK AND ECCENTRIC PATHS.

The crank and eccentric paths are identical; the path of the one is exactly the path of the other. Each revolves around the same centre, namely, that of the main shaft of the engine. The crank and eccentric centres each describe an arc, the length of the chords varying with the circles described. The chord A B described by the crank centre being greater than that delineated by the eccentric

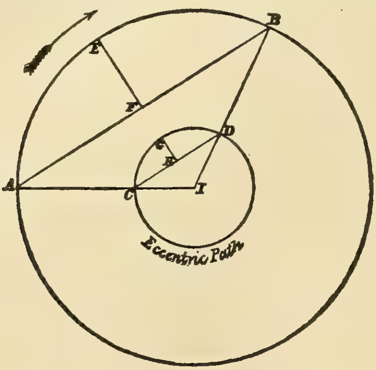


Fig. 64.—The Crank and Eccentric Paths.

A B, Chord of the arc of supply on crank path. C D, Chord of the arc of supply on eccentric path. E F, Versed sine of the chord of the arc of supply on crank path. G H, Versed sine of the chord of the arc of supply on eccentric path. I, Centre of engine shaft.

centre on C D, consequently their versed sines must likewise vary. Thus, in the example, the large circle denotes the path of the crank, and the small circle that of the eccentric; A is the commencing of the IN stroke, and B the point of cut-off determined on. It is very evident that the point A, or crank pin, has travelled from A to B, while that of the eccentric has travelled from C to D; draw the lines A B and C D, bisect A B at F, and draw the lines E F and G H through the centre I. The line E F is the versed sine of the chord for the crank path, and G H is the versed sine of the chord for the eccentric path. In all cases the versed sine of the chord for the crank path must, in

the first place, be found due to the length of the crank and connecting rod, as likewise the point of cut-off; then when the versed sine of the eccentric is likewise known, which equals the opening of the port by valve, minus one-half of the lead, then the eccentric circle can be found by the rule of three (based on the known property that the versed sines of circles of similar segments are as the diameters of the respective circles). Thus, supposing the crank circle was 18 inches in diameter, the versed sine E F being 4 inches, while the versed sine G H is $1\frac{1}{4}$ inch: we have

$4 : 18 :: 1{\cdot}25 = 5{\cdot}62$ inches diameter of the eccentric circle.

THE CRANK AND ECCENTRIC PATHS DELINEATED AS REGARDS THE COVER, LEAD, AND CUT-OFF.

The length of the eccentric rod being not less than six times the throw of the eccentric, the versed sine of the chord described by the arc on the eccentric path equals the opening of the port by valve, minus one-half of the lead nearly. Thus, supposing the versed sine of the chord of the arc of supply on the crank path was 4 inches, the opening of the port by valve $1\frac{1}{2}$ inch, and, for the sake of illustration, the lead or opening of the port at the commencement of the stroke of the piston is $\frac{1}{2}$ inch, we have $1\frac{1}{2} - \frac{1}{4} = 1\frac{1}{4}$ inch, the versed sine of the chord of the arc of supply of the eccentric.

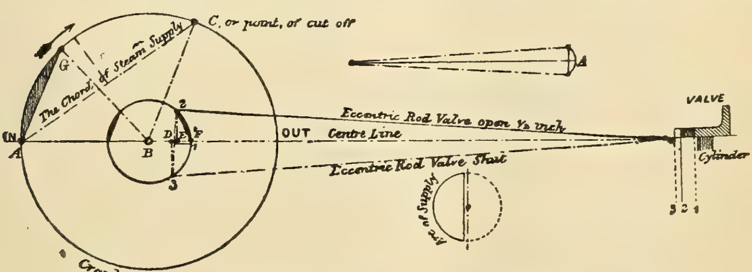


Fig. 65.—The Crank and Eccentric Paths delineated as regards the cover, lead, and cut-off.

Let A B represent the line of the crank at the commencement of the IN stroke; as the point A or crank pin travels from A to C, the point of cut-off, it is evident that the valve must open and shut while the crank-pin centre describes the arc A C. It is therefore necessary to lay off the eccentric centre on the opposite side of the path, as at F. Set off F E, which equals the full opening of the port

by valve, minus the lead, or 1 inch; this is the distance from E to F. Then set off E D, the lead equals ½ inch, while the remainder of the radius of the eccentric circle, or B D, equals the outside cover or the lap of the valve. With the length of the eccentric rod as the radius from E, the point 2 on the valve can be determined; this, for sake of illustration, is measured from the edge of the valve, instead of the pin on the valve rod for taking the eccentric rod, and from the edge of the valve, as at 2, cut the eccentric path at 2, and from the point D fix the point 3 on the valve; cut as before the point 3 on the eccentric path, join the line from 2 to 3 on its path; that line is the chord of the arc of supply by eccentric. It will thus be seen that the figures on the eccentric path correspond with the figures on the valve; thus the point 2 gives the lead, the point 1 the full opening of the port by valve, and at the point 3 the valve has returned and just covers the port, this being the point of cut-off, or no more steam is admitted into the cylinder, the remainder of the stroke of the piston being actuated by the expansive force of the steam in the cylinder. It will thus be seen that when the crank centre is at the commencement of the IN stroke, as at A, the port is open ½ inch; when the crank pin centre travels to G the port is full open, and the valve returning, until the crank centre has travelled to C, then the cut-off takes place, the valve having closed the port; thus the expansion of the steam in the cylinder commences. This only provides for the IN stroke; that for the OUT stroke must be found in like manner, and it will be seen that with the same throw of the eccentric the opening of the steam port by valve is less for the OUT stroke than for the IN stroke; consequently the lap for the OUT stroke must be greater than for the IN stroke. When great nicety is required, the area of the port on the cylinder should be arranged for the OUT stroke, and the length of the port for the IN stroke reduced accordingly, so as to get equal area of port for IN and OUT stroke, as likewise equal cut-off in the cylinder. Thus when the versed sine of the chord of the arc of supply is given for the crank path, and the versed sine of the chord of the arc of supply can be determined, it becomes an easy matter for the student to practically delineate the various points of the crank and eccentric paths in relation to each other.

To find the versed sine of the eccentric rod, working to the formula $V = R - (\sqrt{R^2 - C^2})$ [V = versed sine, R = radius, C = semi-chord], we can take as follows:—Throw off the eccentric, or the

diameter of the circle of the eccentric pulley centre, round the centre of the crank shaft ($C \times 2) = 50$ parts. Eccentric rod, 300 parts in length (R); opening of port, 20 parts; lap, 5 parts.

$$300^2 = 90000;\ C = 25;\ C^2 = 625.$$

Then taking $90000 - 625 = 89375$, and $\sqrt[2]{89375} = 299-$. Then V or the versed sine would but equal $300 - 299-$; or $1 \times$: equal to but $\frac{1}{50}$ of the entire travel of the valve.

DOUBLE ECCENTRICS AND LINK MOTION.

The mode of setting out the link motion for the marine engine differs but little from that pursued for the locomotive type. With the former the double eccentrics and link are simply introduced, so as to get a convenient arrangement for handling the engines, the link being rarely used to work with varying expansion, it being either full up or full down. The reversing lever in general makes

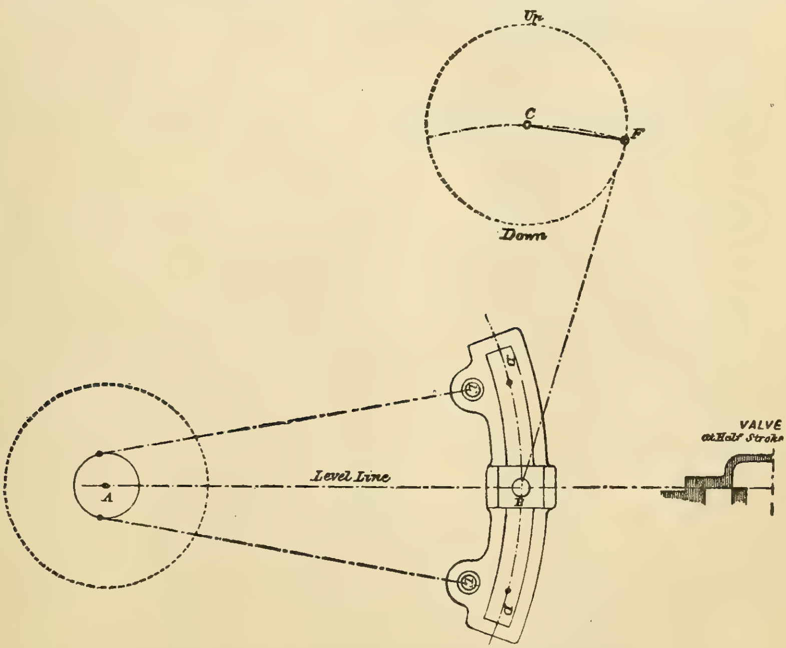


Fig. 66.—Double Eccentrics and Link Motion for the Marine Engine.

a half revolution around its axis, the point of suspension on the lever being either up or down, the link being in full gear for the for-

ward or backward motions, as the case may be. In some instances the lifting or reversing lever only describes a small arc of a circle, having the radius of the lever much longer than by the former arrangement; then the point of suspension is at some intermediate part of the half circle; in fact, just similar to the examples given for the locomotive engine in the preceding pages. In all examples the most convenient method of setting out the link is by placing the valve and adjuncts at half stroke, A being the centre of the crank shaft, and B the centre of the pin on the valve spindle for taking the block on which the link slides. With the radius A B describe the arc D D; this is the centre line of the curve of the link; make the distance between the pins for taking the eccentric rods, as at E E, equal to three times the throw of the eccentric or diameter of the path. Then from the point B, with a convenient length of lifting rod as the radius, describe the arc C F; it gives the position at the half lift of the link of the reversing lever, or, as in the main connecting rod for the engine, the vertical distance from B to C is the length of the lifting rod, the radius of the lifting arm C F being half of the distance between the centres of the pins on the link for the eccentric rods. Thus we have given the leading points to attend to in setting out the double eccentrics and link motion.

THE LAP OF THE VALVE VARIES AS THE CUT-OFF AND LENGTH OF CONNECTING ROD.

With the opening of port by valve, and the lead remaining the same, the lap of the valve must vary as the cut-off. The less the chord and versed sine of the arc of supply becomes on the crank path the greater is the chord of the arc of supply on the eccentric. The figure shows the chord of the arc of supply on the crank path in plain lines, while the eccentric circles are delineated by dotted lines. The line A A is the opening of port by valve, while the curved line represents the laps for the various points of cut-off. It will be seen that when the steam is cut off at five-eighths of the stroke of the piston that the valve at B has less cover than at C; or when the steam is cut off at five-eighths of the stroke the valve requires less lap than for cutting off at the half stroke of the piston, and so on increasing the diameter of the eccentric path. The diameter of the sheave likewise increases rapidly, more especially when cutting off at one-eighth

part of the stroke of the piston, when we have, as in the figure, the diameter of the eccentric path much greater than the diameter of the crank path. It thus becomes apparent that the valve must be

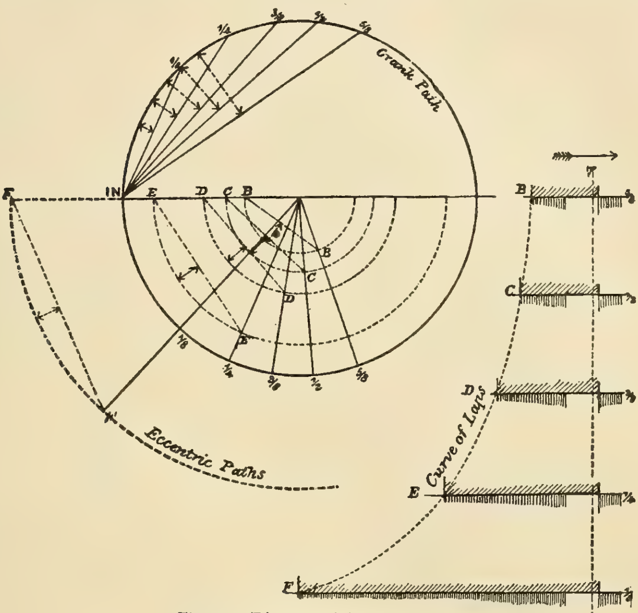


Fig. 67.—Diagram of the Lap of Valves.

altered, the multiple-ported type being adopted. Thus, by introducing three steam ports at each end of the valve, with one central exhaust port, we gain the same area of port on the valve, while the opening of each port is only one-third of that of the single-ported arrangements, so when the steam is cut off at one-eighth or one-fourth part of the stroke of the piston, a valve should be adopted having three steam ports at each end, with one central exhaust port, thus greatly reducing the stroke of the valve, and consequently the lap; the lead may be presumed equal, at least as far as a particular engine is concerned. The lead is greater for high-speed heavy pistons than for engines of the locomotive type, some marine engines having $\frac{3}{8}$ inch of lead, and even at times more, according to the weight and speed, while for high-speed light pistons $\frac{1}{16}$ of lead suffices. It must be borne in mind that the length of the connecting rod materially alters the chord of the arc of supply on the crank path. With a short rod the chord becomes longer, and *vice versa;* and as the versed sine of the chord of the arc of supply on the crank path

must be a known quantity, as likewise the diameter of the crank path, when the opening of port by the valve is determined on, as we now propose to do, the slide valve can be set out as generally adapted for all classes of engines.

OPENING OF PORT BY VALVE.

The diameter of the cylinder and speed of the piston must also be determined on to find the opening of port by the valve. Supposing it is required to find the opening of port by the valve, with a piston speed of 300 feet per minute giving out for a single cylinder 200 nominal horse-power, multiply the constant 33,000 by the power required, and divide the product by the speed of the piston per minute, multiplied by the constant 7 lbs., and the quotient added to half the area of the piston-rod will give the number of square inches of cylinder area; thus,

$$\frac{33000 \times 200}{300 \times 7} = 3142 + 28 = 3170 \text{ square inches,}$$

or say $63\frac{1}{2}$ inches, is the diameter of the cylinder, this being the recognized rule for the nominal horse-power of marine engines. For high-pressure engines we simply take the steam pressure in boiler instead of the constant 7 lbs., making an allowance of $1\frac{5}{8}$ of the power required, and the rule for finding the cylinder's diameter is the same as for the marine engine. Thus, supposing the power required was 20 horse, and the speed of the piston 200 feet per minute, with a steam pressure of 30 lbs.,

$$\frac{33000 \times 32 \cdot 5}{200 \times 30} = 178 \cdot 7 = \text{say } 15 \text{ inches diameter.}$$

To find the full area or opening of port by the valve we will take the former example as for the marine engine, namely 3170, as area of the cylinder in square inches, with a piston speed of 300 feet per minute. Multiply the cylinder area by the speed of the piston in feet per minute, and divide the product by the constant 10,000, the quotient gives the area of port by the valve—

$$\frac{3170 \times 300}{10000} = 95 \text{ square inches.}$$

Thus the area of the steam port by the valve, divided by the length of the steam port, will give the opening. The length of the port is found by dividing the cylinder diameter by $1 \cdot 7$; thus, $63 \cdot 5 \div 1 \cdot 7 = 37 \cdot 5$, or say in round numbers 38 inches, is the length

of the port; and again $95 \div 38 = 2{\cdot}5$ inches, this is the linear opening of the port by the valve for a single port. As double-ported valves are generally adopted, the linear opening of each will be 1·25 inches.

The steam ports in the cylinder are much in excess of this, the area for the steam port being $\frac{1}{19}$ of the cylinder area, and for the central exhaust $\frac{1}{8}$ of the cylinder area is generally allowed,—

$$\frac{3170}{19} = 171 \text{ square inches for the steam port,}$$

$$\frac{3170}{8} = 396 \text{ square inches for the exhaust port.}$$

Thus we would have for steam port $171 \div 38 = 4{\cdot}5$ for main steam port on cylinder, but as two are required the width of each will be 2·25 linear inches. As double-ported arrangements have a bridge or strengthening piece on the centre line of the steam port, say $1\frac{1}{2}$ inch broad, we would have four steam ports in the cylinder, 19 inches long and $2\frac{1}{4}$ inches wide. The exhaust or central port in the cylinder is $39\frac{1}{2}$ inches long, and say 10 inches wide, or nearly so, to give the required area, care being taken that the passages into condenser are not contracted.

SETTING OUT THE VALVE FACES.

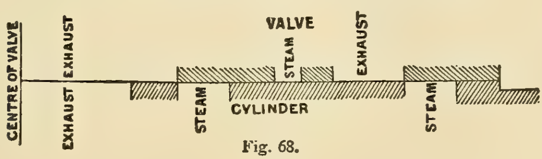


Fig. 68.

	inches.
We will suppose the lap of the valve is	$1\frac{7}{8}$
The width of the outer steam ports on cylinder	$2\frac{1}{4}$
The width of the outer exhaust port equals the half travel of valve	$3\frac{1}{8}$
The width of face on valve	$1\frac{1}{4}$
The width of the inner steam port	$1\frac{1}{4}$
The lap of valve for inner steam port	$1\frac{7}{8}$
The width of inside steam port on cylinder	$2\frac{1}{4}$
The width of face on cylinder	$1\frac{3}{4}$
The half width of exhaust port	5
	$20\frac{5}{8}$

$20\frac{5}{8} \times 2 = 41\frac{1}{4}$ inches, is the length of the slide valve.

The face on the cylinder between the outer and inner steam ports is found as follows:—

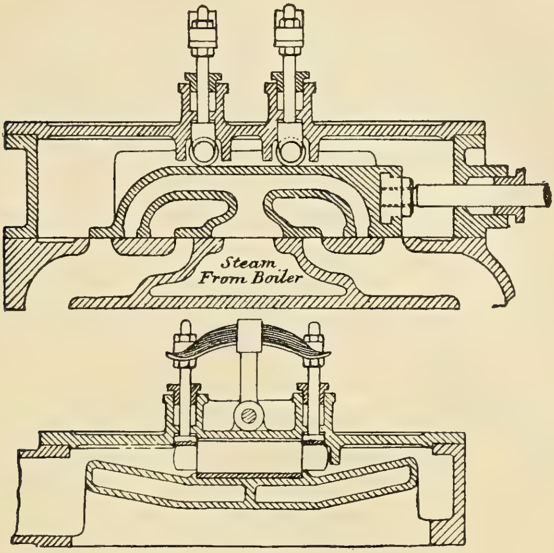
	inches.
The outside exhaust port on valve	3⅛
The width of the narrow face on valve	1¼
The width of the inner steam port on valve	1¼
The inside lap for steam port	1⅞
	7½

Thus the valve and adjuncts can be delineated from the foregoing dimensions. The packing ring on the back should be as large in diameter as the length of the ports will admit of. The rubbing ring on the back of the valve is of brass, while the one the set screws press against is of wrought-iron, a common gasket packing being interposed between the rings. Some have proposed springs along with the packing, with the object of relieving the cylinder in case of priming. It need scarcely be stated that when springs are introduced they must be placed so that the set screws press them against the wrought-iron ring.

RELIEVING THE CYLINDER FROM INTERNAL PRESSURE.

With the desirable object of relieving the cylinder from internal pressure the author has arranged a species of valve differing materially from the double-ported class, having the rings on the back for relieving the valve from back pressure. The arrangement proposed admits the steam from the boiler into the cylinder through the middle port cast on the cylinder, the valve-casing communicating with the condenser. The steam by this plan has a tendency to blow the valve off the face, and to prevent this occurring the valve is provided with a steel plate on the back, let into and securely attached to the valve; rollers bear on this plate, fitted with journals and guide-rods, which pass through the back of the valve-chest cover, having suitable stuffing-boxes perfectly air-tight. There are curved springs secured with mid shackles to the valve-casing cover. These springs have holes drilled at the ends, through which the spindles pass; the ends of the spindles are screwed and fitted with nuts, so that by adjusting the springs any amount of pressure on the valve face can be obtained. It will be seen that, from the steam passing through the valve, the latter is very nearly in equilibrio; still the steam has a tendency to blow the valve from the face. This is counteracted by the rollers, which can be so adjusted as to throw back a little more than the outward pressure; thus the only pressure on the face of the valve is the difference between the outward

pressure of the steam acting on the valve and the pressure imparted by the springs, which can be adjusted to the greatest nicety. This



Figs. 69, 70.—Slide Valve by the Author.

valve requires no packing rings, and should priming occur the cylinders are instantly relieved from the water. This roller motion should work easily and with less friction than the arrangements with packing rings on the back. Should the boiler pressure, too, become higher than the working pressure, this arrangement will act as a safety valve, blowing the steam through the exhaust into the condenser or into the atmosphere, as with high-pressure engines.

RELIEVING THE SLIDE VALVE FROM BACK PRESSURE.

The double-ported valve for high-pressure engines differs very little from those for the marine engine; in fact, the only difference consists in making the exhaust ports at each end of the valve smaller, as likewise the ports in the cylinder may also be reduced in width, and when made very small no packing rings are required, neither is it necessary that marine engines should be so fitted, as with small valves the pressure is not much felt. However, correctly speaking, all valves should be relieved from the back pressure, whether they are double-ported, or simply the original arrangement, with only

three ports in the cylinder. Some of these valves for marine engines simply consist of a frame, having metallic packing rings bearing on the back of the valve casing or cover. In the valve delineated the middle recess is simply formed to lighten the casting as the exhaust steam passes through the valve itself in its passage to the condenser. The packing ring fits into a recess on the back of the valve, a plaited gasket is interposed between the packing ring and a thin metallic plate with springs for pressing the valve and ring to their respective faces. It will be seen that this valve very nearly approaches to what we may term an equilibrium valve. The only objection to this class is that there are two faces to keep tight, and that the ring depends on its accurate fit, along with the gasket packing, to keep it steam-tight. To obviate this difficulty a variety of packing rings have been devised, depending on their metallic contact alone so as to make them steam tight; and as it is an object in some engines of the high-pressure type, having great piston speed, to reduce the weight of the reciprocating parts, the rings have been made very light. An improvement upon the preceding example is that the valve is fitted with a metallic piston, having a spring ring fitted to the piston, the piston and slide valve being pressed to the faces with springs inserted at the bottom of the cylinder, which is cast on the slide-valve. The exhaust, as in the previous example, passes through the valve into the condenser; in such cases it is advisable to fit a brass face on the condenser casting, the steam chest for the valve, as it were, forming part of the condenser, that is, the valve chest and the condenser are cast all in one piece. Another form has the piston and face for pressing to the back of the valve-casing of a lighter section, and the piston made steam-tight with steel-spring rings recessed in the piston. The piston in this arrangement is simply

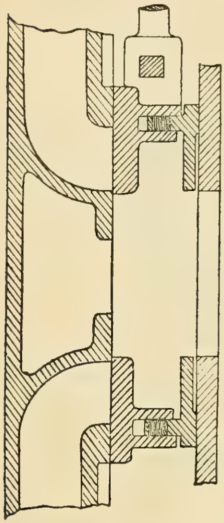


Fig. 71.—Equilibrium Valve.

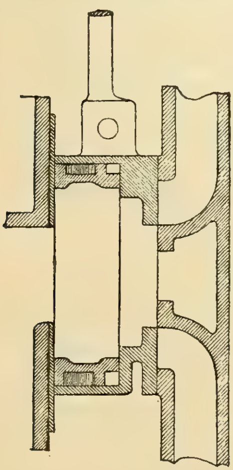


Fig. 72.—Equilibrium Valve.

a ring of metal, the bearing surface on the back of the valve-casing being merely the thickness of the metal forming the ring. It is

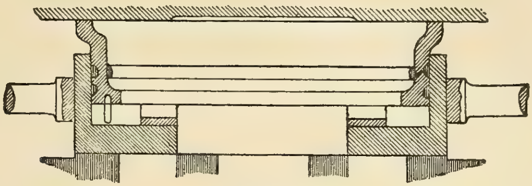


Fig. 73.—Equilibrium Valve.

held to the face on the valve-casing with two flat springs placed inside of the valve, thus pressing the valve and the piston ring to their respective faces. A pin is inserted in the valve and ring to prevent the latter turning round; the valve is fitted with a hoop to which the valve rod is attached. This arrangement is about as effective as any. Some engineers have split the piston ring; others consider, however, that this is not required, as it is a more preferable plan to make the piston steam-tight with light steel rings recessed into the piston as already described, as the ring of itself with a good fit would nearly be steam-tight, while the steel rings make it perfectly so. This valve is admirably suited for the locomotive engine; the rubbing surface on the packing ring is very small, and there can be no doubt that this is a benefit. Care must be taken, however, to have ample provision made for running off any water that may collect when the engine is standing still, so that the narrow rubbing surface may be kept quite dry. In the large marine compound engines, piston valves are now being used.

There are other plans for tightening up the slide-valve rings. The casing, for instance, is provided with a cover on the back, its inside face being truly planed and scraped. To the valve is fitted a ring with snugs cast on it, each snug being provided with a ratchet screw bolt and spring. This ring carries two packing rings, which are pressed up against the valve chest door with the set screws. There are holes tapped in the valve-casing door for the reception of screwed plugs. These holes correspond with the snugs and screws for

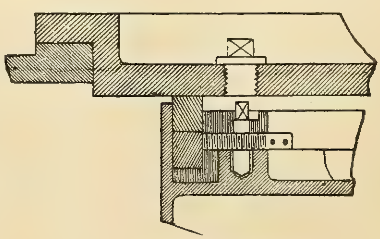


Fig. 74.—Ratchet-bolt for Valve Rings.

tightening up the packing rings, which is done by means of a box spanner inserted through the hole, taking a square part on the screwed studs, which, being turned in a particular way, causes the ratchet to click. Thus the engineer, by counting the number of clicks for each set bolt, can set up the faces equally. It is advisable that the rings should be tightened up under steam, so as to adjust the faces for the expansion of the metals. This plan is neat, but many engineers consider it not nearly so effective as the usual method with plain set screws, packing rings, and plaited gasket, as before described.

To enter into details of an arrangement for taking the pressure off the back of the slide valve, with a piston having an oscillating link, &c., would be of little practical benefit, as such has been very rarely adopted. Suffice it to say, that the piston works in a short pipe accurately bored out, and placed or cast in the valve-casing cover, having a link for connecting the valve; the steam pressure acting on the piston tends to pull the slide-valve from the face. Thus the force is suspended, as it were, on the link pin, and consequently the valve is more easily moved. Sometimes a piston has been introduced to balance the weight of the slide-valve when placed vertically, and no doubt the plan is good when the slide-valve is very large, as the strain on the valve gear is not so much felt. The piston should be fitted with small steel spring rings, thus simplifying the arrangement.

THE INDICATOR DIAGRAM.

When the steam in the cylinder is cut off at any part of the stroke of the piston, and were no condensation taking place, the pressure of the steam at the end of the stroke, or at any intermediate portion of it, could be calculated to a nicety. The curved line that would delineate the steam pressure inside of the cylinder from the point of cut-off would then be quite regular. But in practice there are various causes that tend to make the line of expansion a very irregular figure; for instance, with a slow cut-off, as with the eccentric motion, the line of expansion does not approach so nearly the

theoretical curve as when the valves are suddenly shut off with a cam motion. To ascertain the pressure of the steam in the cylinder, as likewise how the valve acts in its admission, recourse must be had to a very simple contrivance, termed the indicator, or miniature cylinder and piston, similar to that of the engine itself. This instrument, in its original form, has a small cylinder, fitted with a piston and rod. On the top of the cylinder a light spiral steel spring was placed, fixed to the cylinder at one end and to the piston rod at the other end, a pencil fastened to the piston rod moving along with it. The steam pressure raises the piston above a line termed the atmospheric line, and when there is a vacuum in the cylinder the piston is depressed below the atmospheric line. Thus the rising and falling of the piston denotes in the first instance the steam pressure above the atmosphere, and secondly the vacuum below it. A roller is placed alongside, fitted with a pulley, having a cord attached to it; by pulling the cord the roller rotates, and by slackening the cord it returns to its original position, being moved by a spring. The cord is fastened to some reciprocating part of the engine, and by a reducing lever motion is imparted to the roller; thus the full stroke of the piston is taken in miniature, the motion being simply changed from reciprocating action to that of a rotary motion. A roll of paper is fastened round the roller, and secured with a clip. The pencil fastened to the piston rod is made to press on the paper with a slight spring. The cord is moved by hand, and the pencil marks a straight line on the paper, termed the atmospheric line. When the engine is in full working order this line never varies until the steam is admitted by a hand tap to the under side of the piston, which instantly rises, distending the spiral spring according to the pressure of the steam. The roller being in motion, a figure is traced on the paper with the pencil, delineating the pressure on the piston of the engine, above the atmospheric line, as likewise, on the return stroke, marking the vacuum in the cylinder below the line, the spring being compressed by the pressure of the

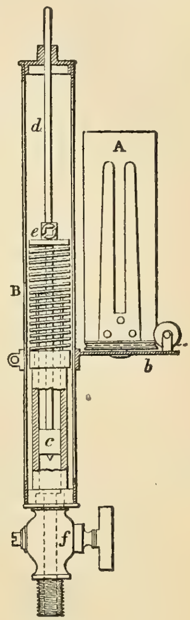


Fig. 75.—M'Naught's Indicator.

A, Roller. *b*, Pulley and cord. *c*, Piston. *d*, Spindle. *e*, Pencil. *f*, Plug-tap.

atmosphere acting on the top of the piston. This is all the indicator can give off, except showing at what part of the stroke the steam is cut off, and the behaviour of the valve in admitting the steam into the

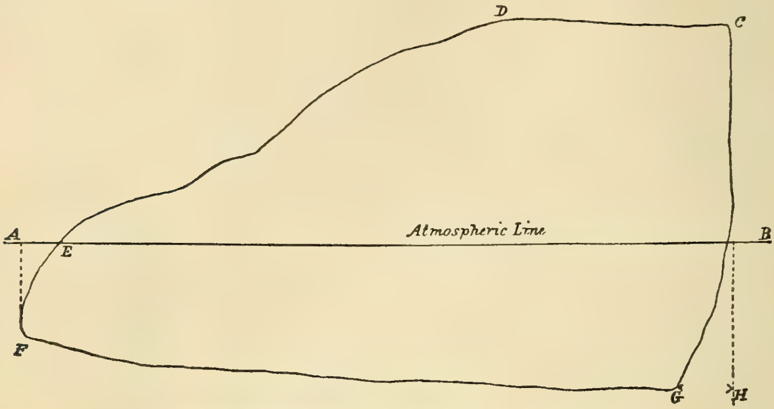


Fig. 76.—Indicator Diagram, from Eccentric Valve Motion.

engine cylinder. Such a diagram is delineated: A B is the atmospheric line, C denotes the pressure above it at the commencement of the stroke, D is the point of cut-off, E is the point where the steam in the cylinder falls to the atmospheric line, F G is the vacuum line, and G H is in compression. The valve has shut the opening from the condenser, and the compressed vapour and steam admitted by the lead of the valve causes the pencil to rise rapidly to the point C on the commencement of the stroke. Then from C to E denotes the steam pressure on the engine piston, and from F to G the vacuum, while G H is the volume of cushioning required to check the motion of the piston at the end of the stroke, in a gradual manner. The amount of compression being greater for a heavy piston having a high velocity than for a lighter piston having the same velocity, bearing in mind that lighter pistons of exceeding high velocity may require more cushioning or opening by valve, technically termed "lead," than heavy ones moving slowly. It must be noted that the point D in the diagram only approximately shows that part of the stroke where the steam ports are entirely shut, or the communication from the boiler cut off by the valve. This defect in the diagram is inherent in all when the valve is actuated on by an eccentric, as the motion of the eccentric is very slow when shutting the ports, while that of the piston is rapid. Thus, to a certain extent, the steam is wire-drawn, so that the pressure in the cylinder is gradually reduced,

and rounds off the diagram, rendering it difficult to define the exact point of cut-off. To illustrate this more fully a diagram is given from an engine fitted with Corlis's valve gear. This species of gear shuts off the steam from the cylinder very quickly. The steam pressure in this example was 50 lbs. per square inch, the cylinders had a diameter of 38 inches, while the speed of the piston was

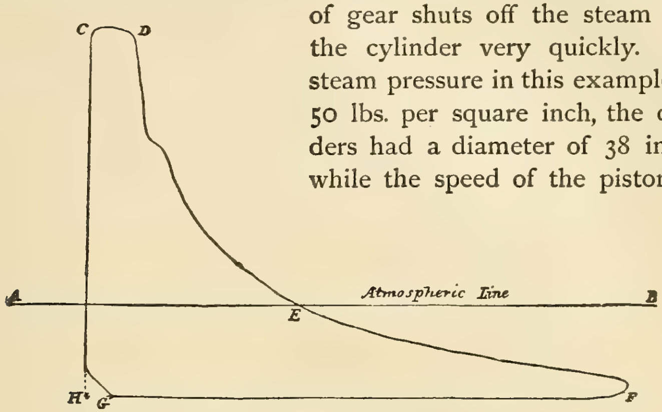


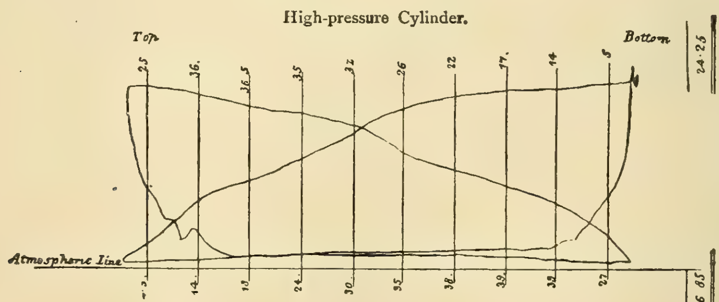
Fig. 77.—Indicator Diagram, from Corlis's Valve Gear.

500 feet per minute. With such high pressure and piston speed the diagram approaches more closely to the theoretical figure than that obtained from a valve actuated by the common eccentric. All manufacturers strive to obtain a diagram from their engines as near the theoretical curve as possible, not that the engine gives out more power or indicated measure, but simply that the valve gear is quick and effective. But as the power given off is measured by the steam pressure and vacuum as taken from the diagram, no one will dispute that a full figure in the diagram indicates less power than a fine figure; on the contrary, more power must be developed, the speed of piston being identical.

The indicator diagram is of great importance to the engineer, as from it he can at once tell the steam pressure in the cylinder as compared with that in the boiler, whether to ascertain the pressure at the commencement of the stroke, or to discover at what part of the stroke the steam is cut off,—to notice if "wire-drawing" occurs, or a sharp cut-off, at what part of the stroke the steam pressure falls to the atmospheric line, and whether the vacuum is quickly and effectually maintained until the point of compression is reached. By comparing the boiler and cylinder pressures, too, he can tell what amount of condensation takes place in the pipes, and adopt means to prevent it. In short—and in this lies the great value of the indicator—by a proper diagram taken off the engine he

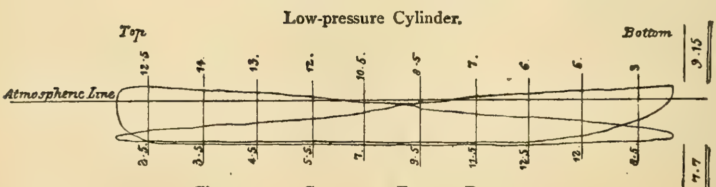
can tell how it is performing its duty. By means of the indicator noting the steam pressure and vacuum acting on the piston, as well as the velocity of the piston, at the time of trial, a true estimate of the working of the engine is obtained, and thus steam users are satisfied and disputes avoided.

Some authorities say Watt invented the indicator, others assert that M'Naught successfully introduced it, although improvements have since been made by others to suit modern high-speed engines. The long stroke of the piston and spiral spring causing the pencil to, as it were, "jump," made the diagram very irregular. To obviate this defect the stroke of the piston was reduced, and the range of the pencil multiplied with a lever parallel motion. Certainly the improvement is very effective, and fully answers the object in view. To suit the varying steam pressures it is found advisable to supply springs of different degrees of power. Thus we have springs for 60 lbs. to the inch, and others 15 lbs. to the inch; and it will thus be understood that when the 60 lb. spring is used, and the steam



Steam, 45 lbs. Vacuum, 28½ inches. Revolutions, 61.

Indicated horse-power,		298·05	H.P. cylinder.
Do.	do.	310·88	L.P. „
		608·93	



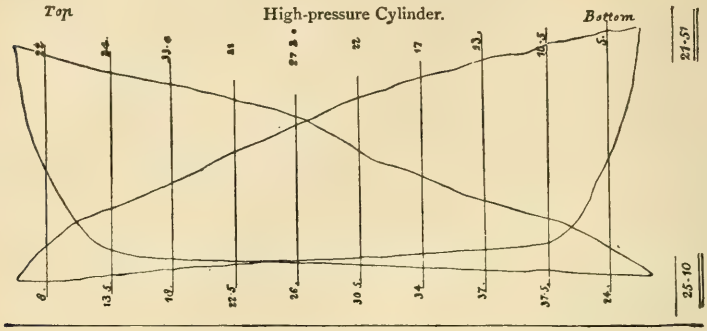
Figs. 78, 79.—Compound Engine Diagrams.

in the cylinders only 15 lbs., that the steam line on the diagram will only be ¼ inch from the atmospheric line, and with the vacuum

proportionately less also; consequently this reduction is obviated by using the 15 lb. spring to suit the pressure in the cylinder of the engine. For compound engines varying springs are necessary; but it is considered that for ordinary marine engines, and in all engines where the variation of the steam pressure is not great, that one scale, and spring to suit, is quite sufficient, as a variety only creates confusion. To show this more fully, take two diagrams from marine engines of the compound type. The full figure shows the behaviour of the steam in the high-pressure cylinder, and the lesser diagram steam in the low-pressure cylinder. The same scale is used for both (the diagrams being reduced from the original). It will be seen that the diagram for the low-pressure cylinder is very lean, while that for the high-pressure cylinder is well defined; and to make the former bolder it is evident that a different spring and scale must be adopted. This would improve the appearance of the low-pressure diagram, but were the same scale and spring adopted for the high-pressure diagram it would make the figure too large. The reading of the high-pressure diagram is somewhat different from ordinary high-pressure engines. The diagram in such cases would show the pressure, commencing from the atmospheric line, while in the example before us there is a slight back pressure. This is due to the steam expanding into the large cylinder instead of into the atmosphere, as with ordinary high-pressure engines.

We give examples in which both the high and low pressure cylinders have diagrams taken from them. Both of the figures are well defined, the scale for the high-pressure diagram being double that for the low-pressure diagram, or the spring of double the power. Thus it will be seen that it is quite necessary to have two sets of springs for combined engines, so that there may not be so great a difference in the diagrams, or that the figure be not too minute in the one nor too bold in the other. When the operator is taking diagrams off an engine he generally takes them for both ends on the same paper, provision being made on the cylinder for doing so, the small steam pipes fitted being in communication with both ends of the cylinder. Thus the double figures are represented, one for the top or OUT stroke, and another for the IN stroke of the piston. Care must be taken that the area of the small pipe connecting both ends of the cylinder is of sufficient size, not less than ¾ inch in diameter, so that the full pressure may be conveyed instantly to the piston of the indicator. This pipe must be fitted with a hand-tap for each end

of the cylinder, so that when one of them is shut the other is open to the indicator, and so on for each end of the cylinder. The examples

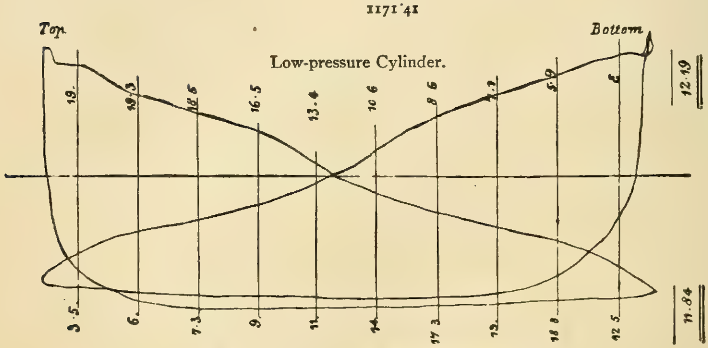


Steam, 54 lbs. Vacuum, 28¾ inches. Revolutions, 60.

Indicated horse-power, 457 66 H.P. cylinder.

Do. do. 713·75 L.P. ,,

1171·41



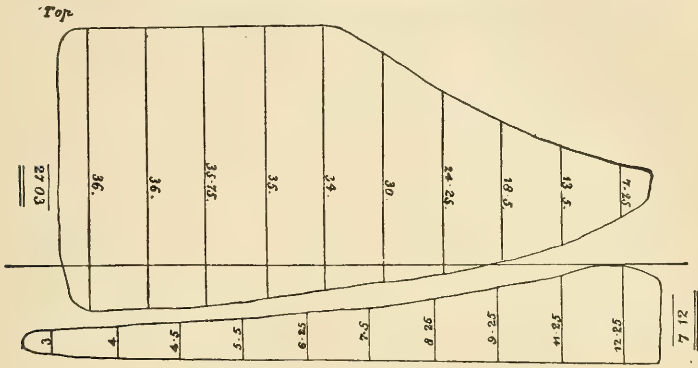
Figs. 80, 81.—COMPOUND ENGINE DIAGRAMS.

illustrated are taken from combined engines of the vertical type; the top and bottom of the cylinders are taken in the literal sense, but the IN stroke of all engines—that is, when the crank is moving inwards towards the cylinder—should be termed the IN stroke, and when the crank is moving from the cylinder the OUT stroke is signified: by adhering to these terms confusion is prevented.

Although the two preceding examples show back pressure on the return stroke of the high-pressure piston, as delineated by the diagrams, yet the expansion may be carried so far that the steam may fall to the atmospheric line at the commencement of the stroke of the large piston or low-pressure cylinder. The following diagrams show that this has taken place in the up or top stroke of the high-pressure piston, the steam expanding to the top of the large

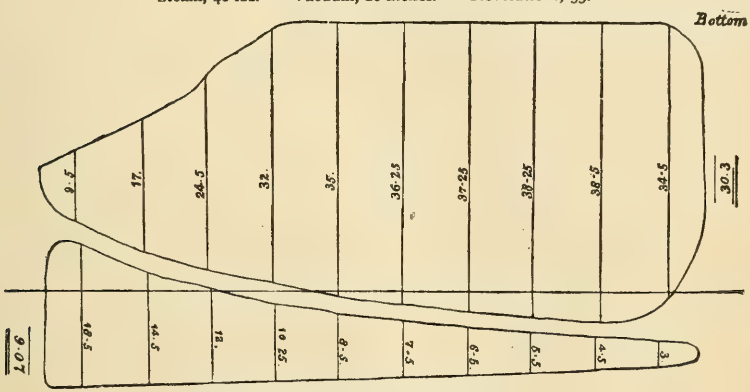
cylinder, or down stroke of the low-pressure piston. For large power this is an advantage, as the descent of the large piston is

High and Low Pressure Cylinders combined.



Total indicated power, 1551.

Steam, 40 lbs. Vacuum, 28 inches. Revolutions, 33.



Figs. 82, 83.—Compound Engine Diagrams.

better balanced than if great steam pressure was admitted into the cylinder. Again, when the steam is raising the small piston, it will be seen that more steam is admitted, the cut-off taking place at a later period. The diagram for the large cylinder shows steam pressure above the atmospheric line for a very short period, which of course is beneficially utilized in raising the large piston. These two diagrams admirably show the action of the slide-valve, the opening of the valve being greater for the IN stroke than for the OUT stroke. This takes place with valves having the same amount of cover on each steam end, actuated by an eccentric motion.

For reading off the steam and vacuum measures the diagram is

divided into ten parts on the atmospheric line; the tenth space is subdivided, having one-half at each end, thus having ten ordinates as shown; so by measuring each ordinate by the scale adopted, the sum of the ordinates divided by 10 gives the mean pressure in the cylinder. The power is run out by the usual formula—

$$\frac{\text{Area of cylinder in square inches} \times \text{mean pressure} \times \text{speed of piston in feet per minute}}{33000};$$

thus the real or indicated power of the engine is obtained.

The theoretical line of expansion of the steam in the cylinder is only useful to show how nearly the diagram as taken by the indicator approaches it. Without comparing the theoretical measure with the diagram illustrated, we will explain how the theoretical line of expansion is obtained. It is based on the natural law that governs pneumatics, namely, that the pressure of an elastic fluid varies inversely as the space into which it is expanded or compressed. Thus if the steam in the cylinder is cut off at one-fourth of the stroke of the piston, the space it occupies at the end of the stroke will be four times the volume of the steam admitted into the cylinder; it has expanded into four times its bulk, and the pressure at the end of the stroke will be only one-fourth of the original volume admitted into the cylinder. To find the pressure of the steam at the end of the stroke, or at any intermediate part of the stroke of the piston, multiply the number of inches the piston has travelled when the steam is cut off by the pressure, dividing the result by the total length of the stroke in inches, or by that portion of it that is required. Thus, supposing A B in the figure represented one-fourth of the stroke, B being the point of cut-off, and the stroke of the piston is 36 inches, with a steam pressure of 20 lbs. per square inch, we would have—

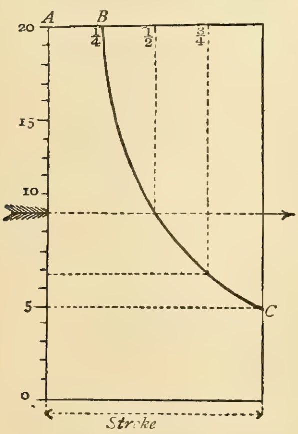


Fig. 84.—Theoretical Diagram.

$\frac{9 \times 20}{36} = 5$ lbs. steam pressure at the end of the stroke,

$\frac{9 \times 20}{27} = 6{\cdot}66$ lbs. steam pressure at three-quarters of the stroke,

$\frac{9 \times 20}{18} = 10$ lbs. steam pressure at one-half of the stroke.

Thus there is one-fourth of the original pressure at the end of the stroke, at three-fourths of the stroke one-third, and at half stroke one-half of the original pressure. The initial pressure will be 20 lbs. cutting off at one-fourth of the stroke of the piston, at one-half it will be 10 lbs., at three-quarters 6·66 lbs., and the terminal pressure will be 5 lbs. The stroke is delineated by the horizontal line in the figure, and the vertical line represents the diameter of the cylinder with the lbs. pressure marked off, the curved line from B to C being the theoretical curve of expansion.

The diagram is taken as follows:—The mechanism attached to the engine for actuating the roller on which the paper is fixed should be of the simplest construction. A plain arm vibrating on a fixed pin, having a slot at the downward end so as to take a pin fixed to the crosshead or piston rod, for direct-acting engines, is by far the simplest arrangement, the cord being attached to the top, a short distance from the vibrating centre. A B in the figure represents the full stroke of the piston, and C D the reduced stroke for the diagram. The cord can be led away with suitable pulleys should the point of attachment to the indicator diverge from the straight line, and it is convenient to have a small pulley, fixed on a ball-and-socket joint, placed next to the indicator, so that the cord from the vibrating lever can be placed at different angles to that of the part interposed between the pulley and the roller on the indicator. For vibrating cylinders, and other arrangements, the cord can be attached to the crosshead, and the motion reduced with a large pulley, a band being wound round it, the length of the band being about equal to the stroke of the engine. This pulley is fitted with a strong spring, similar to a watch-spring, and the strain is imparted to this spring instead of to the delicate one in the instrument. Of course it is necessary to have a smaller pulley on the same spindle, so as to reduce the stroke for the diagram. Any part of the mechanism of the engine can, if corresponding with the motion of the piston, be used as the point of attachment for the cord, and simple levers for reducing the stroke, with direct means of guiding the cord to the pulley on the roller of the indicator, is

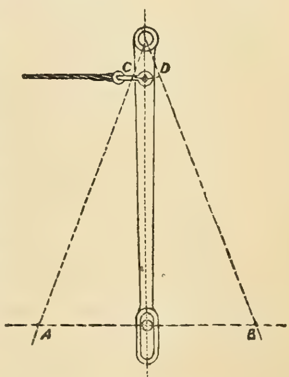


Fig. 85.—Lever for actuating the Roller of Indicator.

far preferable to intermediate pulleys for taking the motion of the reciprocating part to which the cord is fixed. The cord is attached to the instrument with a hook and running eye; thus the exact length of the cord is easily adjusted. The indicator should, if convenient, be fitted to each end of the cylinder, and a diagram taken off for both ends, without having a small pipe in communication with both ends of the cylinder; but when a pipe is fitted it must be of sufficient size, not less than ¾ inch in diameter, so that the pressure may be the same for both ends. If the pipe is made too small, the friction of the steam on the internal circumference materially tends to reduce the pressure on the small piston of the indicator. For vertical engines the plug-tap, for admitting the lubricant into the cylinder for the lubrication of the piston, is provided with a screwed part for taking the indicator, while another plug-tap is fitted to the bottom of the cylinder. These taps are screwed into the covers or ends of the cylinder. For horizontal engines they can be placed on and screwed into the metal surrounding the steam ports; but it is best when they are fitted into the cylinder itself, or at each end on the covers, or otherwise, as the rapidity with which the steam flows through the passages tends to decrease the pressure acting on the indicator piston, although the actual difference may be very minute. Care must be taken that no abrupt bends are made in the small pipe connecting the top and bottom of the cylinder with that of the indicator. Of course there must be a small plug-tap fitted to the pipe, so that the communication from the top is shut off when the operator wishes to take a diagram from the bottom end of the cylinder, and *vice versa.* It is essential that the indicator should be placed vertically, so in some instances large easy bends on the small pipe are admissible, but in all cases where bends are used there must be provision made for running off the water collecting from condensation.

When all is in readiness—the engine going at its accustomed number of revolutions, and all water in the cylinders and pipes ejected, with all the run-off valves shut—the operator turns on the steam to the indicator, the handle for doing so being provided with a stop, so as to have the passage in the plug-tap full open. When the instrument has made a few strokes the cord can be unhooked —the diagram has been taken; and it is only necessary to note on the card the pressure of the steam in the boiler, inches of mercury in the gauge, the number of revolutions, and the scale adopted.

THE EXPANSION OF STEAM.

With a given pressure of steam, and the cut-off taking place at any part of the stroke of the piston, to find the mean pressure exerted on the piston during the stroke, by means of the following table of hyperbolic logarithms. Rule:—Divide the length of the stroke of the piston by the length of the space when the steam is cut off from the cylinder; find in the table the logarithm of the number nearest to the quotient, and add 1 to it: the sum is the ratio of the gain. Then find the terminal pressure by dividing the initial pressure by the proportion of the stroke during which the steam is admitted into the cylinder, and multiply by the logarithm + 1, as above; the product will be the mean pressure exerted on the piston.

Example.— Suppose the length of the stroke to be 24 inches, initial pressure 40 lbs. per square inch, and the steam to be cut off at 6 inches from the commencement of the stroke, we have—

$24 \div 6 = 4$; hyp. log. of 4 is $1·386 + 1 = 2·386$.

Then $40 \div 4 = 10 \times 2·386 = 23·86$ lbs. mean pressure.

HYPERBOLIC LOGARITHMS.

Number.	Logarithm.	Number.	Logarithm.	Number.	Logarithm.	Number.	Logarithm.
1·05	·048	2·05	·717	3·05	1·115	4·05	1·398
1·1	·095	2·1	·741	3·1	1·131	4·10	1·410
1·15	·139	2·15	·765	3·15	1·147	4·15	1·423
1·2	·182	2·2	·788	3·2	1·163	4·2	1·435
1·25	·223	2·25	·810	3·25	1·178	4·25	1·446
1·3	·262	2·3	·832	3·3	1·193	4·3	1·458
1·35	·300	2·35	·854	3·35	1·208	4·35	1·470
1·4	·336	2·4	·875	3·4	1·223	4·4	1·481
1·45	·371	2·45	·896	3·45	1·238	4·45	1·492
1·5	·405	2·5	·916	3·5	1·252	4·5	1·504
1·55	·438	2·55	·936	3·55	1·266	4·55	1·515
1·6	·470	2·6	·955	3·6	1·280	4·6	1·526
1·65	·500	2·65	·974	3·65	1·294	4·65	1·536
1·7	·530	2·7	·993	3·7	1·308	4·7	1·547
1·75	·559	2·75	1·011	3·75	1·321	4·75	1·558
1·8	·587	2·8	1·029	3·8	1·335	4·8	1·568
1·85	·615	2·85	1·047	3·85	1·348	4·85	1·578
1·9	·641	2·9	1·064	3·9	1·360	4·9	1·589
1·95	·667	2·95	1·081	3·95	1·373	4·95	1·599
2·0	·693	3·0	1·098	4·0	1·386	5·0	1·609

HYPERBOLIC LOGARITHMS—*Continued.*

Number.	Logarithm.	Number.	Logarithm.	Number.	Logarithm.	Number.	Logarithm.
5·05	1·619	6·7	1·902	8·35	2·122	9·95	2·297
5·1	1·629	6·75	1·909	8·4	2·128	10·	2·302
5·15	1·638	6·8	1·916	8·45	2·134		
5·2	1·648	6·85	1·924	8·5	2·140	11·	2·397
5·25	1·658	6·9	1·931			12·	2·484
5·3	1·667	6·95	1·938	8·55	2·145	13·	2·564
5·35	1·677	7·0	1·945	8·6	2·151	14·	2·639
5·4	1·686			8·65	2·157	15·	2·708
5·45	1·695	7·05	1·953	8·7	2·163	16·	2·772
5·5	1·704	7·1	1·960	8·75	2·169	17·	2·833
		7·15	1·967	8·8	2·174	18·	2·890
5·55	1·713	7·2	2·974	8·85	2·180	19·	2·944
5·6	1·722	7·25	1·981	8·9	2·186	20·	2·995
5·65	1·731	7·3	1·987	8·95	2·191		
5·7	1·740	7·35	1·994	9·0	2·197	24·	3·178
5·75	1·749	7·4	2·001			28·	3·332
5·8	1·757	7·45	2·008	9·05	2·202	32·	3·465
5·85	1·766	7·5	2·014	9·1	2·208	36·	3·583
5·9	1·774			9·15	2·213	40·	3·688
5·95	1·783	7·55	2·021	9·2	2·219	44·	3·784
6·0	1·791	7·6	2·028	9·25	2·224	48·	3·871
		7·65	2·034	9·3	2·230	52·	3·951
6·05	1·800	7·7	2·041	9·35	2·235	56·	4·025
6·1	1·808	7·75	2·047	9·4	2·240	60·	4·094
6·15	1·816	7·8	2·054	9·45	2·246		
6·2	1·824	7·85	2·060	9·5	2·251	64·	4·158
6·25	1·832	7·9	2·066			68·	4·219
6·3	1·840	7·95	2·073	9·55	2·256	72·	4·276
6·35	1·848	8·0	2·079	9·6	2·261	76·	4·330
6·4	1·856			9·65	2·266	80·	4·382
6·45	1·864	8·05	2·085	9·7	2·272	84·	4·430
6·5	1·871	8·1	2·091	9·75	2·277	88·	4·477
		8·15	2·098	9·8	2·282	92·	4·521
6·55	1·879	8·2	2·104	9·85	2·287	96·	4·564
6·6	1·887	8·25	2·110	9·9	2·292	100·	4·605
6·65	1·894	8·3	2·116				

TABLE OF HYPERBOLIC LOGARITHMS,

TO SUIT GIVEN RATIOS OF EXPANSION.

Portion of the Stroke at which the Steam is cut off.	Ratio of Expansion.	Hyperbolic Logarithm.	Portion of the Stroke at which the Steam is cut off.	Ratio of Expansion.	Hyperbolic Logarithm.
$\frac{1}{10}$	10·	2·3025851	$\frac{6}{10}$	1·66	·5068176
$\frac{1}{8}$	8·	2·0794414	$\frac{5}{8}$	1·6	·4700036
$\frac{2}{10}$	5·	1·6094379	$\frac{7}{10}$	1·42	·3506568
$\frac{1}{4}$	4·	1·3862943	$\frac{3}{4}$	1·33	·2851788
$\frac{3}{10}$	3·33	1·2029722	$\frac{8}{10}$	1·25	·2231435
$\frac{3}{8}$	2·66	·9783260	$\frac{7}{8}$	1·14	·1310284
$\frac{4}{10}$	2·5	·9162907	$\frac{9}{10}$	1·11	·1043600
$\frac{1}{2}$	2·	·6931472			

PROPERTIES OF STEAM AND OTHER GASES.

Pressure, density, and temperature are the important characteristics of steam, as they are the properties which regulate the economical production and application of steam power. Steam as a gas is amenable to the common laws of gaseous fluids; and, according to those laws, the pressure, the density, and the temperature bear fixed relations to one another. The influence of temperature on the expansion of gases under constant pressures is nearly uniform for equal increases of temperature, and is nearly the same for different gases. The expansion of air may be assumed to represent that of other gases, and it is found by experiment that air expands $\frac{1}{490}$th of its volume at 32° for each degree of temperature communicated.

The relation betwixt pressure and volume under constant temperatures is also sensibly uniform within ordinary limits. For an expansion of four times the initial volume, experiments on various gases show a corresponding diminution of pressure in the ratio of 1 to 3·99, or sensibly 1 to 4.

The total or constituent heat of saturated steam is at all temperatures separable into two parts—latent and sensible heat. The sensible heat is that indicated by the thermometer, and it varies as the pressure. The latent heat absorbed during the conversion of water into steam constitutes by far the greater proportion of the total heat. Thus for saturated steam we have the following values:—

Pressure.	Temperature.	Latent Heat.	Total Heat.
14·7 lbs.	212°	966°·6	1178°·6
90 lbs.	320°·2	891°·4	1211°·6

The difference of total heat is, in this case, 33° in favour of the higher pressure. It appears, then, that by expansion perfectly dry steam becomes slightly surcharged, in virtue of the excess of total heat due to higher pressures; and should it contain a portion of water in a state of suspension, a small part of this water must be evaporated during expansion.

For steam, and for gases generally, the following ratios may be adopted:—

With a *constant temperature*, the pressure varies simply as the density, and inversely as the volume.

With a *constant pressure*, expansion is uniform under a uniform

accession of heat, at the rate of $\frac{1}{490}$th of the volume at 32° for each degree of heat. If then we add (490° − 32°) 458° to the indicated temperature, the sum is directly as the total volume by expansion, and inversely as the density.

With a *constant volume*, or density, the increase of pressure is uniformly $\frac{1}{490}$th of that at 32° for each degree of temperature acquired, and adding, as in the previous case, 458° to the indicated temperature, the sum is directly as the total pressure.

Though the law of the formation of saturated steam has been the subject of much and varied experimenting, it can as yet be reached only by the aid of empirical formulas. The weight of a cubic foot of steam at 212°, raised from water under the ordinary atmospheric pressure, namely, 14·7 lbs. per square inch, is ·03666 lbs., and this is an expression of the density of the steam, as weight is a direct measure of mass or quantity of matter. A cubic foot of pure water at 62° weighs 62·321 lbs.; and the ascertained relative volume of saturated steam produced under the atmospheric pressure is 1700 times that of the water at 62° of which it is made; therefore $\frac{1}{1700}$th of the weight of a cubic foot of this water expresses the weight of an equal bulk of the steam so formed, and it is in this way that the weight of steam already noted was determined. From these data, with the aid of the ratios already established, the relations of pressure, volume, and temperature may be found.

To find the relative volume of steam.—Add 458 to the temperature; divide the sum so found by the total pressure, and multiply by 37·3. The product is the relative volume.

To find the total pressure of steam.—Add 458 to the temperature; divide the sum by the relative volume, and multiply by 37·3. The product is the total pressure.

To find the temperature of steam.—Multiply the total pressure by the relative volume, and divide by 37·3; from the quotient subtract 458. The remainder is the temperature.

To find the weight of steam.—Divide 62·321 by the relative volume; the quotient is the weight per cubic foot.

Motion of Steam.—It is well understood that steam unimpeded moves with great velocity from one locality to another, under slight differences of pressure. Steam may flow into a vacuum, or it may deliver itself into the atmosphere, or, further, it may flow into steam of less density. The conditions of its flow in the first and in the other cases are different; as in the second case, for

example, 14·7 lbs., or approximately 15 lbs., of its total pressure go for nothing in counteracting the atmospheric resistance, before the slightest motion is possible. Thus, in the second case, at all pressures the motion of the steam is due solely to the difference of its inherent pressure and that of the atmosphere. The ordinary method of estimating the velocity of the flow of gases or liquids under pressure is founded on the laws of falling bodies; it is a very beautiful application of the law of gravitation, and it yields results simply and directly. A quantity of steam confined in a boiler, of a given pressure and known density, would flow into a vacuum through an opening from the boiler with a certain initial velocity, and this velocity would be the same as that which would be given to a liquid of the same weight as the steam, flowing out under the same pressure. The velocity of efflux referred to, when unretarded by physical obstructions, is precisely that which the liquid would acquire in falling through the height of a column of the same liquid 1 inch square, equal in weight to the pressure of the steam per square inch. By the laws of falling bodies it is known that the velocity, v, acquired in falling freely through any height, h, is equal to eight times the square root of the height, or $v = 8\sqrt{h}$. Thus the velocity of efflux into a vacuum is determinable, and the following is the method of finding it:—

Given, the total pressure of the steam, which we suppose to be saturated, as in all ordinary cases it is; divide the pressure per square inch by the weight of a cubic foot of the steam; the quotient is the height of a uniform column of steam 1 foot square, equal in weight to the pressure of the steam per square inch. Multiply the quotient as found by 144, the number of square inches in a square foot of base, and the product is the height of a 1-inch column of the steam, equal in weight to the given pressure of that steam on the square inch.

To find the velocity with which saturated steam flows freely into a vacuum.—Divide the total pressure per square inch in lbs. by the weight of a cubic foot of the steam in lbs., and find the square root of the quotient; multiply this result by 96. The product is the required velocity in feet per minute.

To find the velocity with which saturated steam freely flows into the atmosphere, or into steam of inferior pressure.—Take the difference of pressures of the two steams for the effective pressure, divide the effective pressure in lbs. per square inch by the weight of a cubic

foot of the denser steam in lbs., and multiply the square root of the quotient by 96. The product is the required velocity in feet per second.

To find the pressure to which saturated steam is reduced when it flows freely, with a given velocity, from one vessel into another.—Multiply the square of the velocity in feet per second by the weight in lbs. of a cubic foot of steam of the initial total pressure, and divide the product by 9216. The quotient thus found expresses the difference of the initial and final pressures; subtract this quotient from the given initial pressure, and the remainder is the reduced total pressure sought.

Of the loss of pressure generally which accompanies the movements of steam.—It has been seen that a reduction of pressure, great or small, necessarily accompanies even the free motion of steam, the difference being consumed in communicating that motion. By far the heaviest losses are, however, due to the resistances of bends and surface friction of pipes, &c. It has been found from experiment on stationary engines and boilers that the losses on various accounts follow these general ratios.

The difference of pressures in the boiler and cylinder is—

1st. As the density of the steam, and as the square of the speed of piston.

2d. As the square of the ratio of area of piston to cross section of steam pipe.

3d. As a factor dependent on bends and friction.

The permanent difference of pressure caused by passing through a stricture in a pipe, otherwise of uniform diameter before and behind the stricture, is as the density of the steam, and as the square of the difference of speeds through the larger and smaller parts of the pipe.

The friction of a fluid through a pipe appears to vary more or less—

1st. As the length directly.

2d. As the diameter inversely.

3d. As the square of the velocity directly.

4th. As the density directly.

PROPERTIES OF SATURATED STEAM AT DIFFERENT PRESSURES.

Pressure in lbs. per square inch above the pressure of the atmosphere.	Temperature in degrees of Fahrenheit.	Total Heat in degrees of Fahrenheit.	Cubic inches of water to produce 1 cubic foot of Steam, according to Pambour.	Volume of Steam produced by 1 of water.		Weight of 1 cubic foot of Steam in lbs.
				Pambour.	Other Authorities.	
1	216·3	1179·9	1·09	1572	1515	·0397
2	219·5	1180·9	1·16	1487	1431	·0419
3	222·5	1181·8	1·22	1410	1357	·0442
4	225·4	1182·7	1·28	1342	1290	·0465
5	228·0	1183·5	1·35	1280	1229	·0487
6	230·6	1184·3	1·41	1224	1174	·0510
7	233·1	1185·0	1·47	1172	1123	·0532
8	235·5	1185·7	1·53	1125	1075	·0554
9	237·9	1186·5	1·59	1082	1036	·0576
10	240·2	1187·2	1·65	1042	996	·0598
11	242·3	1187·9	1·71	1005	958	·0620
12	244·4	1188·5	1·77	971	926	·0642
13	246·4	1189·1	1·84	939	895	·0664
14	248·4	1189·7	1·91	909	866	·0686
15	250·4	1190·3	1·95	881	838	·0707
16	252·2	1190·8	2·02	855	813	·0729
17	254·1	1191·4	2·07	830	789	·0751
18	255·9	1192·0	2·13	807	767	·0772
19	257·6	1192·5	2·19	785	746	·0794
20	259·3	1193·0	2·25	765	726	·0815
21	260·9	1193·5	2·31	745	707	·0837
22	262·6	1194·0	2·37	727	688	·0858
23	264·2	1194·5	2·43	709	671	·0879
24	265·8	1195·0	2·49	693	655	·0900
25	267·3	1195·4	2·55	677	640	·0921
26	268·7	1195·9	2·61	661	625	·0942
27	270·2	1196·3	2·67	647	611	·0963
28	271·6	1196·8	2·72	634	598	·0983
29	273·0	1197·2	2·78	621	585	·1004
30	274·4	1197·6	2·84	608	572	·1025
31	275·8	1198·0	2·89	595	561	·1046
32	277·1	1198·4	2·95	584	550	·1067
33	278·4	1198·8	3·01	573	539	·1087
34	279·7	1199·2	3·07	562	529	·1108
35	281·0	1199·6	3·13	552	518	·1129
36	282·3	1200·0	3·18	542	509	·1150
37	283·5	1200·4	3·24	532	500	·1171
38	284·7	1200·8	3·30	523	491	·1192
39	285·9	1201·1	3·36	514	482	·1212
40	287·1	1201·5	3·41	506	474	·1232
41	288·2	1201·8	3·46	498	466	·1252
42	289·3	1202·2	3·52	490	458	·1272
43	290·4	1202·5	3·58	482	451	·1292
44	291·6	1202·9	3·64	474	444	·1314
45	292·7	1203·2	3·70	467	437	·1335

PROPERTIES OF SATURATED STEAM—*Continued.*

Pressure in lbs. per square inch above the pressure of the atmosphere.	Temperature in degrees of Fahrenheit.	Total Heat in degrees of Fahrenheit.	Cubic inches of water to produce 1 cubic foot of Steam, according to Pambour.	Volume of Steam produced by 1 of water.		Weight of 1 cubic foot of Steam in lbs.
				Pambour.	Other Authorities.	
46	293·8	1203·6	3·75	460	430	·1356
47	294·8	1203·9	3·81	453	424	·1376
48	295·9	1204·2	3·86	447	417	·1396
49	296·9	1204·5	3·92	440	411	·1416
50	298·0	1204·8	3·98	434	405	·1436
51	299·0	1205·1	4·03	428	399	·1456
52	300·0	1205·4	4·09	422	393	·1477
53	300·9	1205·7	4·14	417	388	·1497
54	301·9	1206·0	4·20	411	383	·1516
55	302·9	1206·3	4·25	406	378	·1535
56	303·9	1206·6	4·30	401	373	·1555
57	304·8	1206·9	4·36	396	368	·1574
58	305·7	1207·2	4·41	391	363	·1595
59	306·6	1207·5	4·47	386	359	·1616
60	307·5	1207·8	4·53	381	353	·1636
61	308·4	1208·0	4·58	377	349	·1656
62	309·3	1208·3	4·64	372	345	·1675
63	310·2	1208·6	4·69	368	341	·1696
64	311·1	1208·9	4·74	364	337	·1716
65	312·0	1209·1	4·81	359	333	·1736
66	312·8	1209·4	4·86	355	329	·1756
67	313·6	1209·7	4·92	351	325	·1776
68	314·5	1209·9	4·96	348	321	·1795
69	315·3	1210·1	5·02	344	318	·1814
70	316·1	1210·4	5·08	340	314	·1833
71	316·9	1210·7	5·12	337	311	·1852
72	317·8	1210·9	5·18	333	308	·1871
73	318·6	1211·1	5·23	330	305	·1891
74	319·4	1211·4	5·30	326	301	·1910
75	320·2	1211·6	5·43	323	298	·1929
76	321·0	1211·8	5·40	320	295	·1950
77	321·7	1212·0	5·45	317	292	·1970
78	322·5	1212·3	5·52	313	289	·1990
79	323·3	1212·5	5·57	310	286	·2010
80	324·1	1212·8	5·62	307	283	·2030
81	324·8	1213·0	5·66	305	281	·2050
82	325·6	1213·3	5·72	302	278	·2070
83	326·3	1213·5	5·77	299	275	·2089
84	327·1	1213·7	5·83	296	272	·2108
85	327·8	1213·9	5·89	293	270	·2127
86	328·5	1214·2	5·95	290	267	·2149
87	329·1	1214·4	6·00	288	265	·2167
88	329·9	1214·6	6·06	285	262	·2184
89	330·6	1214·8	6·10	283	260	·2201
90	331·3	1215·0	6·14	281	257	·2218
91	331·9	1215·2	6·21	278	255	·2230
92	332·6	1215·4	6·26	276	253	·2258

PROPERTIES OF SATURATED STEAM—*Continued.*

Pressure in lbs. per square inch above the pressure of the atmosphere.	Temperature in degrees of Fahrenheit.	Total Heat in degrees of Fahrenheit.	Cubic inches of water to produce 1 cubic foot of Steam, according to Pambour.	Volume of Steam produced by 1 of water.		Weight of 1 cubic foot of Steam in lbs.
				Pambour.	Other Authorities.	
93	333·3	1215·6	6·32	273	251	·2278
94	334·0	1215·8	6·37	271	249	·2298
95	334·6	1216·0	6·42	269	247	·2317
96	335·3	1216·2	6·47	267	245	·2334
97	336·0	1216·4	6·52	265	243	·2351
98	336·7	1216·6	6·57	263	241	·2370
99	337·4	1216·8	6·62	261	239	·2388
100	338·0	1217·0	6·67	259	237	·2406
101	338·6	1217·2	6·72	257	235	·2426
102	339·3	1217·4	6·77	255	233	·2446
103	339·9	1217·6	6·82	253	231	·2465
104	340·5	1217·8	6·88	251	229	·2484
105	341·1	1218·0	6·93	249	227	·2503
106	341·8	1218·2	6·99	247	225	·2524
107	342·4	1218·4	7·04	245	224	·2545
108	343·0	1218·6	7·11	243	222	·2566
109	343·6	1218·7	7·17	241	221	·2587
110	344·2	1218·9	7·23	239	219	·2608
111	344·8	1219·1	7·26	238	217	·2626
112	345·4	1219·3	7·32	236	215	·2644
113	346·0	1219·4	7·38	234	214	·2662
114	346·6	1219·6	7·45	232	212	·2680
115	347·2	1219·8	7·48	231	211	·2698
117	348·3	1220·2	7·57	228	208	·2735
119	349·5	1220·6	7·68	225	205	·2771
121	350·6	1220·9	7·78	222	202	·2807
123	351·8	1221·2	7·84	219	199	·2846
125	352·9	1221·5	8·0	216	197	·2885
127	354·0	1221·9	8·11	213	194	·2922
129	355·0	1222·2	8·22	210	192	·2959
131	356·1	1222·5	8·3	208	189	·2996
133	357·2	1222·9	8·42	205	187	·3033
135	358·3	1223·2	8·51	203	184	·3070
145	363·4	1224·8	9·04	191	174	·3263
155	368·2	1225·1	9·54	181	164	·3443
165	372·9	1227·7	10·04	172	155	·3623
175	377·5	1229·1	10·53	164	148	·3800
185	381·7	1230·3	11·0	157	141	·3970

Note.—According to Rankine and others, the relative volume of steam is less than has been commonly assigned to it by Pambour, following the laws already explained; Pambour having treated steam as a permanent gas, instead of as being, what it is in actual practice, highly saturated.

STATIONARY ENGINES.

PUMPING ENGINES FOR MINES.

One of the earliest and still a principal use of the steam-engine

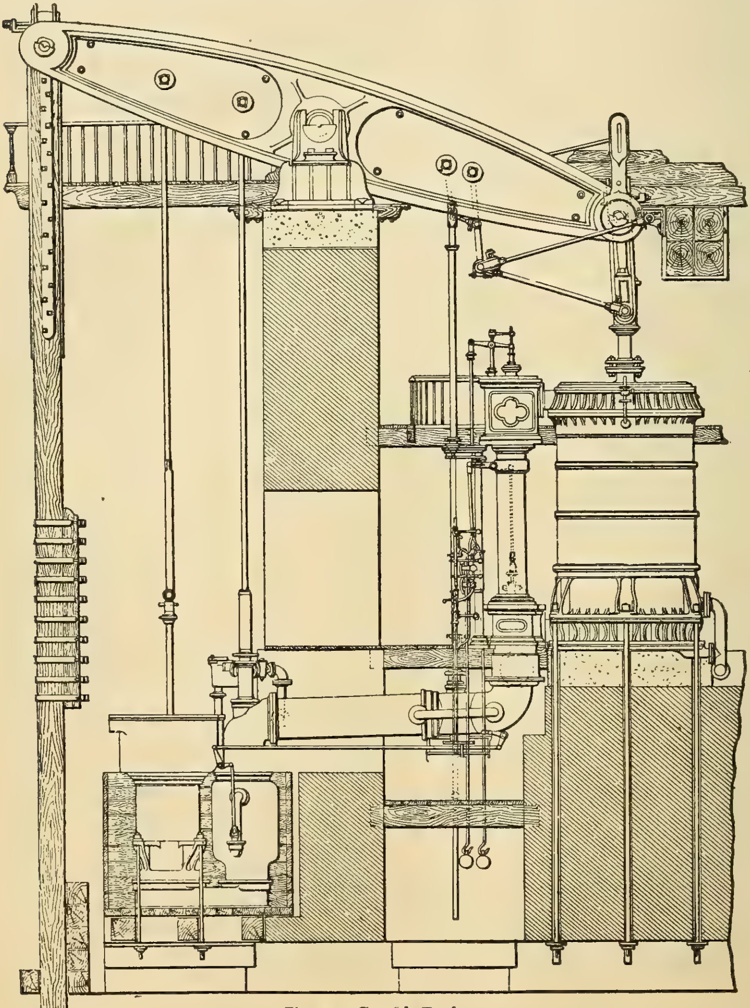


Fig. 86.—Cornish Engine.

is for pumping the water out of the mines from which we obtain

our coal, ironstone, and other ores. There would be great difficulty in reaching those vast stores of hidden treasure without the powerful aid of the steam-engine, which enables us to overcome many of the risks and difficulties encountered in mining operations.

The single-acting beam engine is generally adopted for pumping the water from great depths. These great beams of cast-iron—and in some cases of wrought-iron plates, stiffened with angle or T-iron—are supported by pillow blocks, resting on a wall of masonry carried up to a convenient height above the top of the cylinder. The beam is in two halves, with gudgeons between them, and is connected to the piston-rod of the steam cylinder by a crosshead

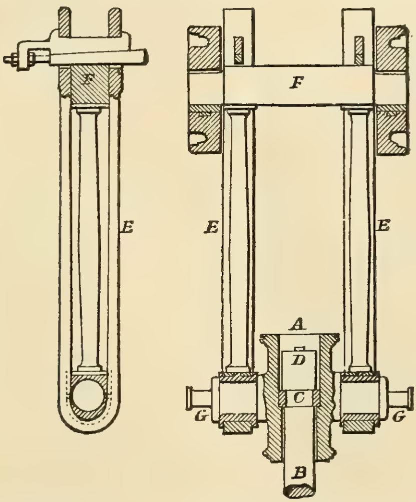


Fig. 87.—Crosshead and Side-links of Parallel Motion for Piston-rod of Cornish Engine.

A, Crosshead. B, Piston rod. C, Loose collar. D, Key. E, Links. F, Beam gudgeon. G, Bearings for parallel bars.

and parallel motion; and in some instances the crosshead of the piston-rod works in suitable cast-iron guides, and is connected to the beam gudgeons by plain links. This motion is not so expensive in first cost, and the wear and tear is greatly reduced.

The cylinder A is a plain casting with port C cast on at the top, incased in an outer cylinder B, to which it is bolted, flanges being cast on each at the top for that purpose. The outer casing or cylinder is bolted to a separate bed-plate D at the bottom. A space is left between the two cylinders for the admission of steam from the boiler; and they are made steam-tight at the bottom, raised strips

being cast on each, and turned slightly conical. A small branch pipe is cast on the outer casing at the top for the admission of the steam, which forms a steam-jacket around the internal cylinder, and one at the bottom to run off the water from the condensation of the steam in the annular space between the two cylinders; each of these pipes is fitted with a plug tap. The bed-plate D is a strong casting, with port E cast on, and is bolted down through the foundations with six holding-down bolts. There is a bottom plate F fitted into and made tight by a rust joint. The cylinder cover G is an open casting, with separate covering plate H, and has the stuffing-box I cast on, which is fitted with the usual lantern brass K, and gland L, for the packing of the piston rod. The piston M is also an open casting, ribbed at the under side, and fitted with a junk ring N, having bolts with nuts recessed in the body of the piston; there are two spring packing rings O, of cast iron, accurately turned and made perfectly steam-tight. The piston rod is let in through the under side, and is turned conical, fitting into a corresponding hole in the piston, the rod being secured with a cotter P at the top. The cylinder is fitted with a ring Q of wood at the bottom, to deaden the shock should the piston descend so far.

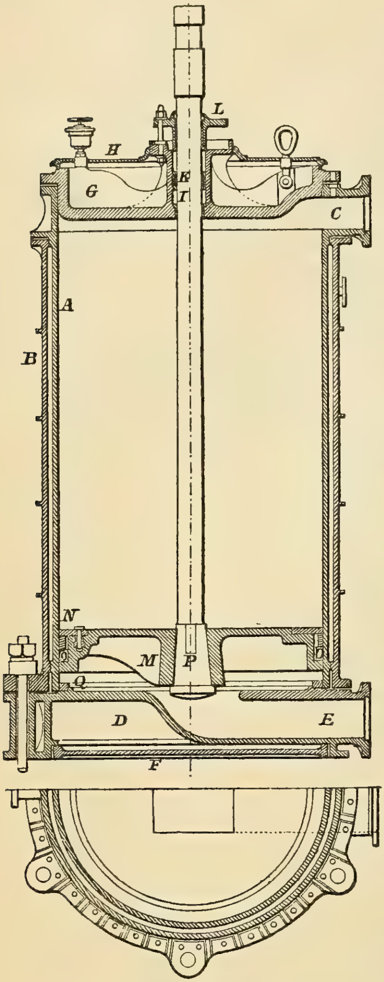


Fig. 88.—Cylinder, Piston, &c.

The pump rods are directly attached to the gudgeon at the other end of the beam by suitable wrought-iron straps, jib, and key. The end of the pump rod is covered by plates on each side, fastened by cross bolts passing through and through, to prevent the wood strip-

ping. The pump rods of timber bend to the versed sine described, but being of great length the motion is but little felt.

The pumps are of two kinds—lifting or bucket pumps and for-

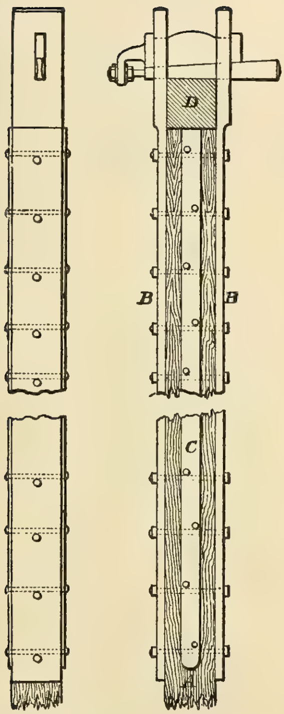


Fig. 89.—Pump Rod of Cornish Engine.

A, Wooden rod. B B, Wrought-iron straps, with jib and cotter. C, Side plates. D, Beam gudgeon.

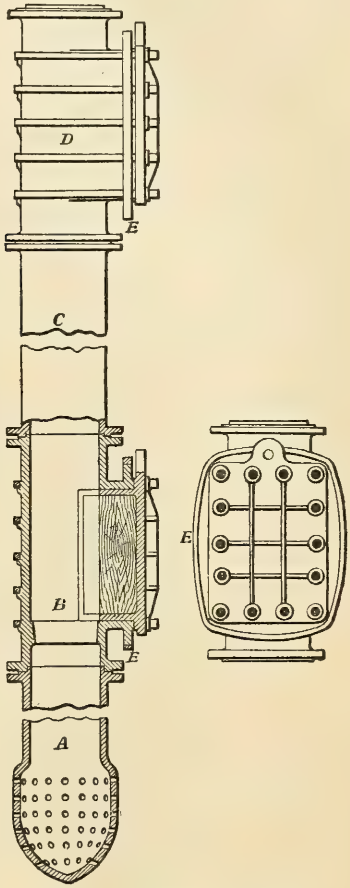


Fig. 90.—Lifting Set. Bucket, 18 inches in diameter.

A, Suction pipe. B, Suction-valve chest. C, Working barrel. D, Delivery-valve chest. E, Wrought-iron strap shrunk on.

cing or plunger pumps; and in some instances a combination of the solid bucket and plunger pump is adopted.

In the former of these, as indeed in all pumps, the water is forced up the pipe by the pressure of the atmosphere, when a few strokes of the pump bucket have caused a partial vacuum in the pump barrel. The suction valve should be placed somewhat less

than 30 feet from the surface of the water in the shaft or pit to be drained, 28 feet being a convenient height; that is to say, when the water passes through the valve to the top of a solid bucket. But when a hollow bucket is adopted, with the discharge valve fitted thereto, the distance from the level of the water to the height to which the bucket ascends in the pump barrel should not exceed 28 feet; consequently the suction valve in the pipe will be lower down. In the former of these arrangements the water is drawn through the suction valve on the down stroke of the solid bucket, and in the up stroke the suction valve closes, and the water is discharged through a valve placed in the stand pipe above the suction valve, until the return or down stroke of the bucket, when the discharge valve closes simply by the weight of water upon it; the

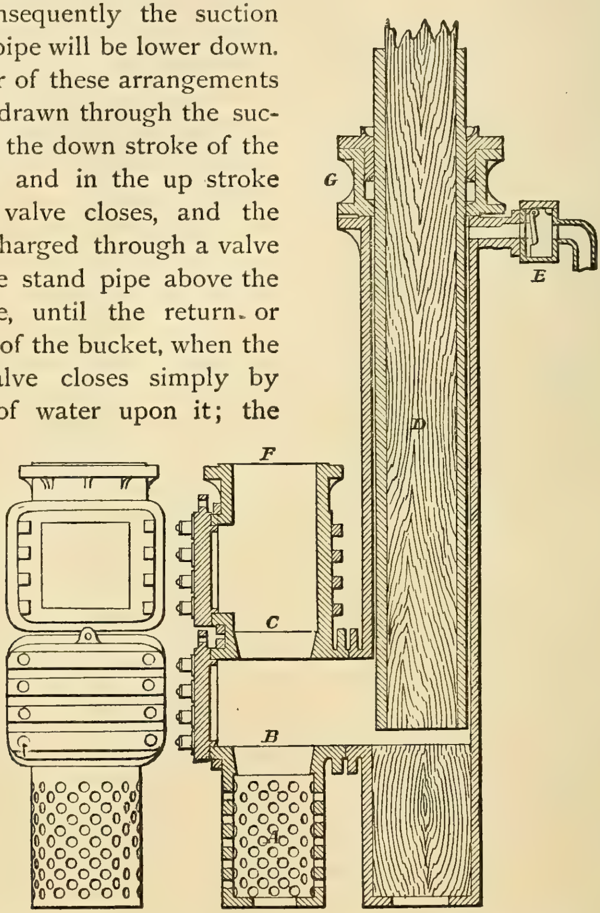


Fig. 91.—Forcing Set. Plunger 18 inches in diameter, arranged with one door for each valve. A, Suction pipe. B, Suction-valve seating. C, Delivery-valve seating. D, Plunger. E, Air valve. F, Stand pipe. G, Stuffing-box piece and gland.

suction valve then opens, and the pump barrel is filled as before; and so on. With the hollow bucket the water is drawn through the suction valve in like manner, but with this difference, that the

bucket is ascending, consequently it is discharging and drawing the water into the pump barrel at the same time, and the down stroke of the bucket simply allows the water above the suction valve to pass through the valve fitted to the bucket, to be again discharged as already explained.

The force or plunger pump is just a vertical arrangement of that type universally used as feed pumps for all classes of engines, the upward stroke of the plunger, after the vacuum is fully established in the pump barrel, drawing the water through the bottom valve, and discharging it through the top valve fitted to the stand pipe. The height to which the bottom of the plunger ascends should not exceed 28 feet, as in the previous example; and the suction and discharge valves should be arranged below that height. It is evident that this pump will discharge a column of water equal to the area of the plunger and length of its stroke, as indeed do all pumps, whether they are lifting or forcing sets. It is found advisable, however, to fit a small valve opening outwards, so as to discharge the air collecting at the top of the barrel, and consequently a little water is ejected at each stroke. The plunger is a plain cylinder turned all over, and secured directly to the wooden pump rod; the rod is turned, and then driven tightly in and wedged with iron wedges at the ends, a collar

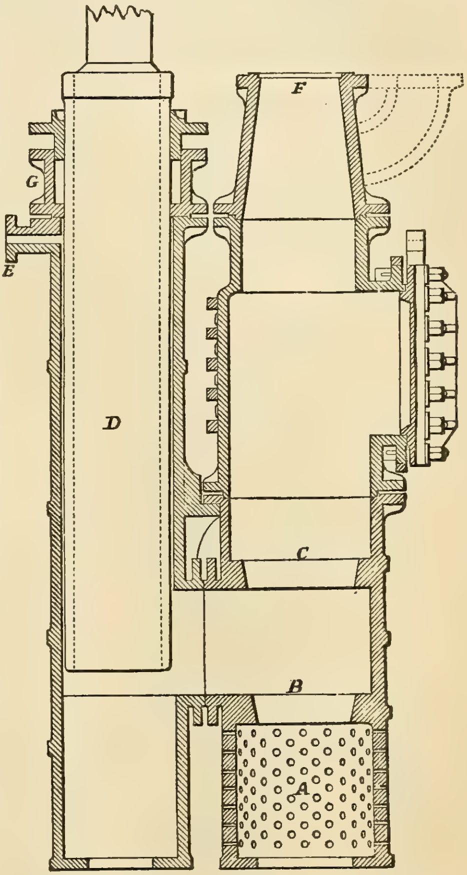


Fig. 92.—Forcing Set. Plunger 23½ inches in diameter, arranged with one door for both valves.

A, Suction pipe. B, Suction-valve seating. C, Delivery-valve seating. D, Plunger. E, Branch from air valve. F, Stand pipe. G, Stuffing-box piece and gland.

being left at the top. All the flanges of the pump fittings should be bracketed, and the valve-chest doors strongly ribbed in the casting, and secured with deep nuts, the hoop bolts passing round the valve chest, the flanges having strong wrought-iron hoops shrunk on. The arrangements shown are very compact; the bottom of the pump resting on the cistern placed high up above the lifting set, the suction pipe of the latter (Fig. 90) being as long as possible in order to make provision for inspecting the valves in the event of the water accumulating or rising at the bottom of the shaft; the valves also are so arranged that in the event of the water rising above the doors they can be drawn out from the surface for inspection, and again placed in.

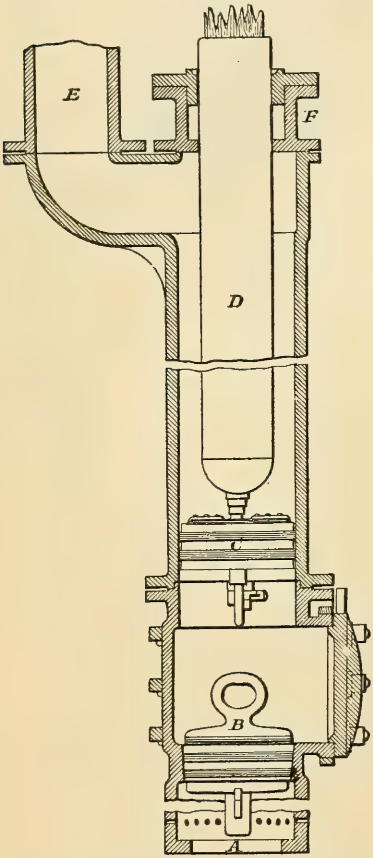


Fig. 93.—Combined Plunger and Bucket Pump.
A, Suction pipe. B, Clack or suction valve. C, Bucket. D, Plunger. E, Stand pipe. F, Stuffing-piece box and gland.

In the combination of the solid plunger and bucket pump the water delivery is equalized; the barrel is accurately bored out, and fitted with a gland at the top for the plunger to pass through, making it perfectly air and water tight. The area of the plunger is exactly one-half of the area of the pump barrel, consequently at the down stroke, the barrel being full of water, it is forced through the valve in the bucket; and the water being forced into one-half of the space, one-half of the contents of the pump is discharged in the down stroke and one-half in the up stroke. The plunger in this arrangement can be made to act as an air vessel, thus the flow of the water is very regular, and the shock of the valves becomes somewhat easier. This pump can be arranged with a solid piston, having suction and delivery valves as in ordinary pumps. There must, however, be a passage in connection with the top of the barrel

of the pump and the discharge pipe, and in this way the water at the down stroke of the piston, being forced through the discharge valve, one-half flows above the piston and the other half is discharged up the stand pipe; until the up stroke takes place, when the other half is also discharged. Thus in the up stroke the piston is drawing the water up the suction pipe, filling the pump barrel and discharging one-half of its cubical contents at one and the same time; while during the down stroke the water is forced out of the barrel, one-half of it fills the vacuity above the piston and the other half is discharged. It will thus be seen that a smaller stand pipe will suffice for this class of pump; and where the flow of water from the pump requires to be uniform, this arrangement has a decided advantage over the foregoing examples. At the bottom of the air pipe a suction piece is fitted, having a number of holes of about 1 inch in diameter, to prevent extraneous matter lodging in the pump and destroying the proper action of the valves. All classes of pumps are so fitted, and lifting sets have in some cases a foot valve placed at the bottom of the air or suction pipe.

In connection with the stand pipe and suction pipe in lifting arrangements with solid bucket a small pipe is fitted, having a branch to the space between the suction and the top valve. The object of this pipe is to allow water from the stand pipe to flow into the pump and suction pipe, as at times, when the pumps are not working, the water would flow past the valves, and were not the air in the pipes ejected by the water flowing in from the stand pipe, the shock to the machinery would be very great. There are three plug valves, one on each end of the small pipe and branch, to shut the water off when the pipe and pump are full, which is known by the small pet plug tap placed below the discharge valve passing water—a sure sign that all the air is expelled. At the bottom of the suction pipe a loaded valve is placed a little above the water in the well, or *sump*, the technical term for the space below the roadway at the pit bottom where the water is collected. This valve is loaded to a pressure of 15 lbs. per square inch, and is used to test the action of the valves. Should the suction valve be passing water when the solid bucket is lifting, the valve will discharge water, simply because the water sucked up the air pipe is forced down again, and as it cannot pass the foot valve when in good working order, it naturally escapes at the loaded valve, where the pressure on the valve is not so great as on the discharge

valve, subjected as it is to the full head of water in the stand or delivery pipe. This valve can also be used to test if the discharge valve closes properly, the engine being stopped for that purpose; the plug tap above the suction valve and the one on the air pipe are opened, and a communication through the small pipe already mentioned is effected between the pump and the suction pipe. If the discharge valve passes water the loaded valve at once lifts, being acted on by the full hydrostatic head in the delivery pipe. This valve is therefore of great use in testing the efficient working of the pump.

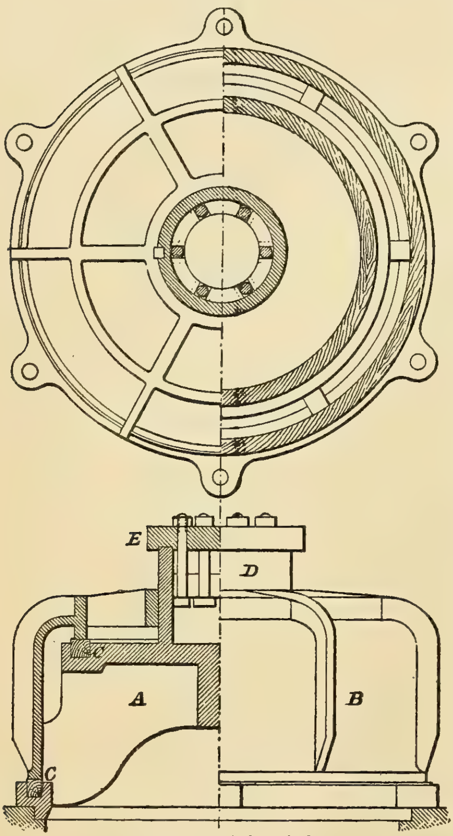


Fig. 94.—Double-beat Valve.

A, Valve seat. B, Valve. C C, Wooden beats. D, Guide piece. E, Flange and bolts.

The pump valves are generally of the double or treble beat kind. They are introduced to obviate the objections inherent in the flap and conical type of valve, due to the great lift necessary in the former to pass the water, and also on account of the full head of water in the stand pipe, which, acting on a large area, causes the valve to shut with great violence, tending to shatter the machinery and foundations. This evil is greatly obviated in the double-beat valve, as it is adapted to pass a large body of water with a moderate lift, which is the principal object to be attained in all valves subjected to hydrostatic pressure. The valve consists of a metallic cylinder, contracted at the top, having a central ring with arms radiating from it, and passing down the side of the cylinder to strengthen it; there is an inside projection at the top of the valve, which is truly faced in the turning lathe, as is also the bottom edge

of the cylinder, the central ring being accurately bored out. The seating consists of a bottom ring and a solid disc at the top, having a guiding piece at the top of the disc, with a loose flange secured by bolts; the bottom ring and disc plate are connected by feathers or arms, cast all in one piece. The bottom ring and top plate are recessed for the reception of a ring of wood or soft metal, termed the beating surface. The amount of contraction at the top of the valve is due to its weight, and the pressure brought to bear on it should be slightly in excess of the total weight of the valve. Thus very little force is lost in lifting it; and as the head of water in the discharge pipe only acts on a small area, in comparison to the water way through the bottom ring—and as the lift of the valve is moderate, owing to the water being forced or drawn through two circumferential openings —the beat on the wooden or white metal rings, if so fitted, is very gentle and but little felt, in comparison with that of flap valves made of leather, fitted with metallic facings to prevent the leather being forced through the seatings. For moderate lifts, however, and more especially for lift pumps, the flap valve is still used.

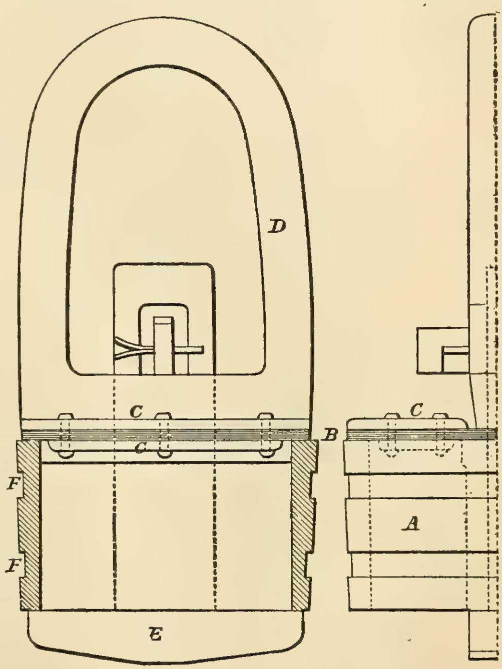


Fig. 95.—Clack Valve with Leather Hinge.

A, Clack seat. B, Leather disc. C C, Top and bottom plates. D, Bow. E, Cross piece with cotter for securing the bars. F F, Recesses.

The top and bottom valves, or *clacks*, as they are technically termed, have deep seatings of cast iron, turned slightly conical, fitting into corresponding parts bored out in the pump castings, and are fixed in position with thin red lead and spun yarn laid into recesses turned out on the circumference of the seat; there is a single feather cast along with the seat, having an oblong hole in the centre.

The valve is a disc of leather, with top and bottom plates of wrought iron, securely rivetted through and through, and it is held in position by a central bar of iron, with long projections on the under side for taking the entire diameter of the valve. A key is driven through the bar, drawing it up against the under side of the seating, which likewise presses down the bar placed on the top of the leather; thus the valve hinges, as it were, on the mid feather, and is perfectly water-tight. The valve is prevented from opening too far by pieces forged on the bar, and at the top of the bar a bow is formed, for attaching a hook and chain when drawing the clack from the surface, as provision must be made that the clack can be drawn when the water is above the valve-chest door. Some of these valves hinge on a bar, which passes through lugs forged on the top plate and through holes in the bow, for fishing the valve to which the bow is securely bolted; there is also a wrought-iron piece at the centre of the valve seating on which the valve hinges. There should be a slight play in the holes to suit the varying thickness of the leather forming the valve.

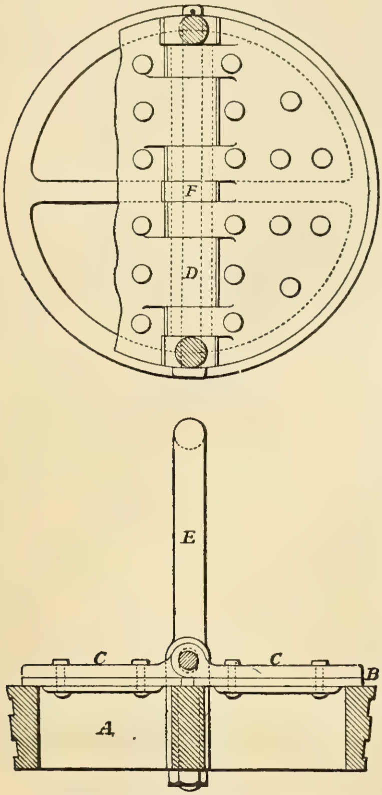


Fig. 96.—Clack Valve with Wrought-iron Hinge Plates.

A, Clack seat. B, Leather disc. C C, Hinge plates. D, Round bar for hinge. E, Bow. F, Centre stud.

The working bucket (Fig. 97) is constructed similarly to the ordinary clack valve with leather hinge, having means of attaching the bar to the pump rods; and is packed with deep rings of gutta-percha, let into recesses formed on the outside circumference, and pressed against the barrel with hydraulic pressure, holes being bored from the top of the bucket for this purpose. This plan is much more preferable than the old mode of packing the bucket with a plaited gasket or ring of leather.

The *economy* of the single-acting pumping engine depends on the high steam pressure adopted—the higher the pressure in the boiler is the less water is required to be evaporated or boiled off propor-

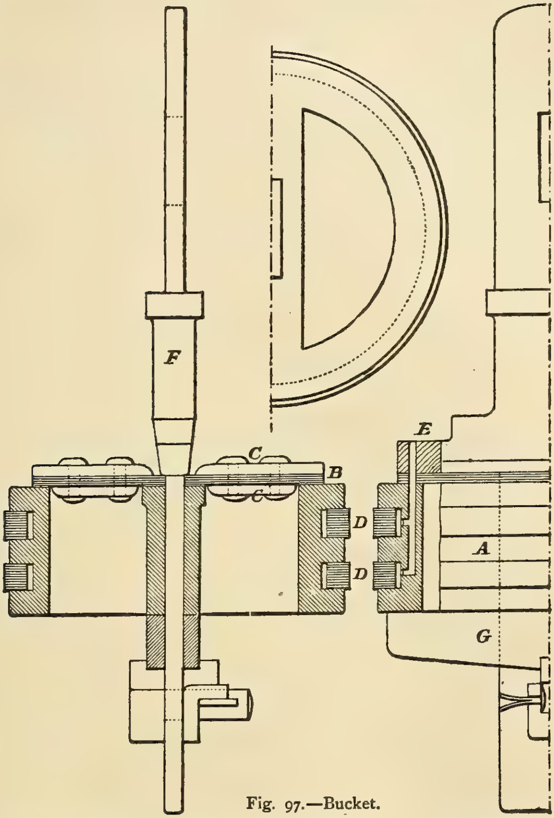


Fig. 97.—Bucket.

A, Bucket. B, Leather disc. C C, Top and bottom plates. D D, Gutta-percha rings. E, Holes for water pressure for the packing rings. F, Rod. G, Cross bar for securing the rod with jib and cotter.

tionally; and, in addition, the facility of cutting off the steam at any part of the stroke to suit the load on the engine, and the careful clothing of all the parts where radiation takes place with a non-conducting material, keeping those parts warm and the surrounding atmosphere cool. To effect this the cylinder is surrounded with a steam casing or outer cylinder. Steam is admitted between these two, and the outer one is covered with felt and wood over all, and in some cases brickwork; the cylinder cover is hollow, admitting steam, and it is protected with wood *lagging*, as it is technically termed. The

steam pipes are covered with felt and canvas, and the valve chests with felt and wood, neatly covered in with ornamental plates. The boilers are protected with fire-brick or other material on the top. Thus, with all these precautions, very little radiation takes place, even although the engine may not have been working for a considerable time.

The *action* of the single-acting pumping engine is quite different from that of the reciprocating engine, having the connecting rod coupled to a crank shaft. The steam from the boiler only acts on the top of the piston, lifting the water at the other end of the beam, or as it were the IN-stroke of the pump, when lifting pumps are fitted;

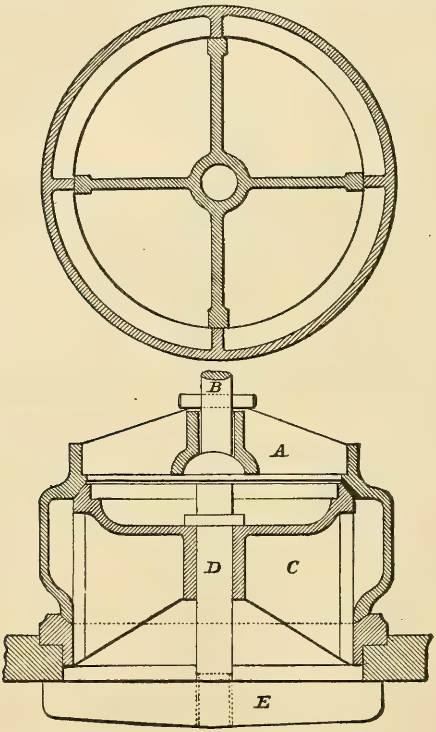


Fig. 98.—Equilibrium Valve.

A, Valve. B, Spindle for valve. C, Seat for valve. D, Holding-down bolt. E, Cross bar.

and when forcing sets are used in connection with lifting pumps, as is often the case when pits are very deep, the water is forced up the stand pipe by the mere weight of the pump rods, &c.

The valves are of the equilibrium kind; two are fitted to the top

chest, namely, the steam and equilibrium valves, and the exhaust valve is placed in the bottom chest. There is likewise, in some examples, a regulating valve worked by hand, for regulating the supply of steam from the boiler; and a throttle valve is placed in

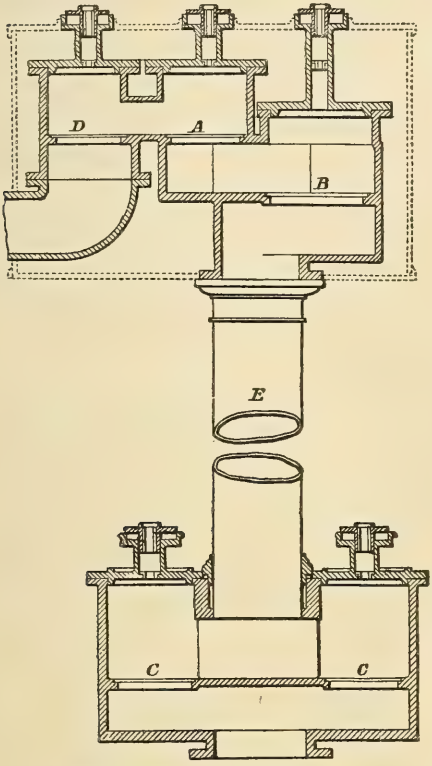


Fig. 99.—Nozzle-valve Chest boxed in.

A, Steam-valve seating. B, Equilibrium-valve seating. C C, Exhaust-valve seating. D, Regulating-valve seating. E, Pipe for conveying the steam from the top to the bottom of the cylinder.

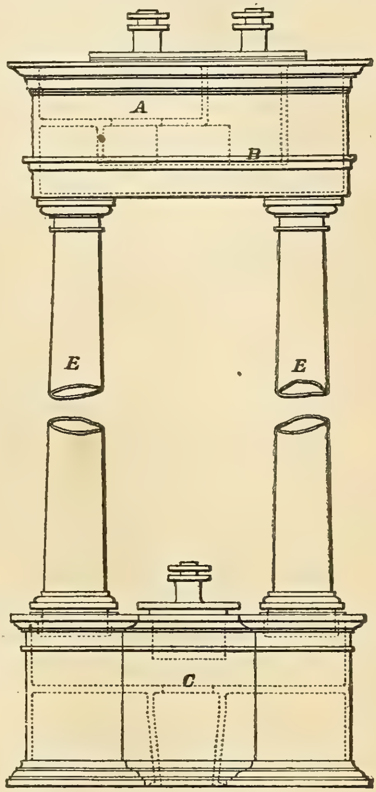


Fig. 100.—Nozzle-valve Chest not boxed in.

A, Steam-valve seating. B, Equilibrium-valve seating. C, Exhaust-valve seating. E E, Pipes for conveying the steam from the top to the bottom of the cylinder.

the pipe communicating with the top and bottom valve chests, which is also regulated by hand, and is introduced to throttle, or rather wire-draw the steam after passing through the equilibrium valve; thus the engineman can control the upstroke of the piston with the greatest nicety without requiring to alter the lift of the equilibrium valve.

There are three shafts or arbors placed across the engine, arranged one above another in a vertical line; the top one is for the steam-

valve gear, the middle one for the equilibrium, and the bottom shaft for the exhaust-valve gear. An arm is keyed on each shaft, having a connecting rod coupled to the lever for lifting each valve; each shaft has also an arm with a connecting rod passing downwards to a loaded lever, the weight of which lifts each valve respectively.

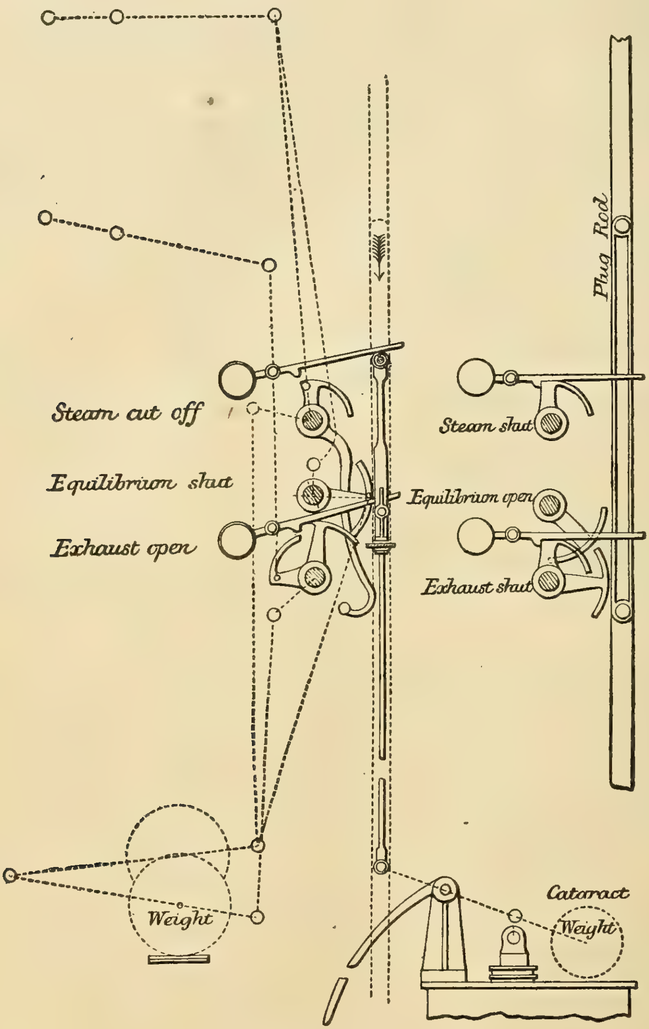


Fig. 101.—Cornish Valve Gear.

The valves are shut with tappets placed on the vertical rod worked by the engine, and named the plug rod; the tappets act on slide

handles or horns keyed to each shaft. The tappet or sliding bar for the steam valve is a long wrought-iron bar, quite parallel in its entire length, secured to the plug rod with eyes at the ends, and set screws passing through these eyes, the point of the screw pressing against the plug rod. This is necessary, as the steam may be cut off quickly, or say at one-fourth of the stroke of the piston, consequently the bar would require to be somewhat more than three-fourths of the stroke of the plug rod, so as to keep the steam valve shut. The two other tappets are round arms, secured to the plug rod in the same way, having a series of leather washers screwed up against a collar, with a nut and metal washer at the end of the projecting bar. On the steam and exhaust shafts a catch and paul are fitted for each, keeping the valves shut until released by the cataract, which consists of a pump worked by the down stroke of the plug rod, with a weighted lever so arranged that the oil or water is forced out of the pump, the delivery being regulated by a valve or plug tap. On the end of the weighted lever there is a rod passing upwards for raising the pauls, which can be adjusted at pleasure; thus the catches are freed, and the weight arm lifts the valve. A quadrant is keyed on the middle and bottom shaft to keep the equilibrium valve shut. When the exhaust valve is open the top quadrant abuts on the lower one, and keeps the equilibrium valve shut until it is released, when the tappet for the bottom shuts off the exhaust, and allows the quadrant to pass the equilibrium quadrant, thus releasing it, and the valve is instantly opened by the weight arm.

Now we will suppose the piston at the top of the cylinder, and the exhaust valve full open by the cataract releasing the bottom catch; the cataract rod, still moving upwards, releases the top catch, and the steam valve is instantly raised by the weight-arm, the piston at once descends, until the long parallel tappet cuts off the steam; the plug rod still moves on until one of the tappets shuts the exhaust at the end of the piston stroke, and as the equilibrium valve was held in position by its quadrant, at the moment the exhaust is shut the equilibrium valve opens; so the steam is thus allowed to escape from the top of the piston to the under side of it, the descent of the pump rods placed at the other end of the engine beam being regulated by the amount of opening of the equilibrium valve, which can be further regulated by the throttle valve at pleasure wire-drawing the steam in the passages from the top to the under side of the

piston; and in this way the outgoing stroke or descent of the pump rods may be very slow indeed. The plug rod, ascending, shuts off the equilibrium valve, thus stopping the further descent, or producing only a slight motion, of the plunger and weight, until the cataract releases the exhaust and then the steam valve. It will thus be seen that for a part of the downward stroke the steam and exhaust valves are both open, and the exhaust remains so until the end of the stroke, when it is closed; while in the up stroke of the piston the equilibrium valve is open, and all the rest shut off.

In order still further to explain this intricate valve gear, in Figs. 102, 103, we give an example fitted to an engine at one of our Cornwall mines, the diameter of the steam cylinder being 90 inches. "The action of the gear will be better understood if we describe each stroke separately. First, the steam, or *indoor* stroke:—This is the down stroke of the piston, and is produced by the admission of steam through a valve termed the steam valve, situated in the top nozzle, and which is actuated by means of the lever B fixed on an arbor carried in bearings in the two upright castings at the sides, which are termed arbor posts. It is usual to connect the lever B directly with the steam-valve lever—by means of a rod carried upward, instead of indirectly by means of a rod carried downwards, as in the example before us; the reason for the latter arrangement we will explain as we go on. The lever B is attached by means of a rod with a 'treadle' or weighted lever of wood situated under the engine-house floor; the treadle is connected to the steam-valve lever, so that when the lever B is raised it closes the steam valve. On the steam arbor, or the arbor carrying the lever B, is placed a quadrant K, which is supported by means of the catch U, which catch keeps the steam valve closed till the cataract rod A shall have released the quadrant K by means of the lever M, and thus allowed the weighted treadle to pull down the lever B and open the steam valve. The cataract is actually the governor of the engine, and acts in the following way. (See illustrations of cataracts, Figs. 104, 105, 106.) In this case a plunger is attached to the lever, on the opposite side of the fulcrum is placed the cataract rod A, and on the plunger side of the fulcrum a weight. The plunger works in a kind of force pump, fixed in a cistern full of water. When the plunger is raised water follows it up through the suction valve, and during the down stroke the water thus drawn from the cistern is forced back again through a delivery valve which is capable of being

varied in the height of its lift by means of a screw on the cataract governor valve rod, which rod is under command of the engine-driver. It is evident that the smaller the opening of the delivery valve the slower will the plunger descend, the weight forcing it being constant. As the plunger descends the rod A rises, and brings the roller shown in the front elevation to bear on the lever M, and thus releases the quadrant K. Let the cataract plunger be up, then the engine is at rest, and remains so until the rod A shall have raised the lever M and released the catch U; the weight attached to B then suddenly falls and opens the steam valve. Steam being suddenly let in on the piston causes it to commence its *indoor stroke*, and in doing so to give a downward direction to the motion of the plug rod S, the tappets of which coming into contact with the steam horns depress them, and thus raising the lever B close the steam valve, at the same time the piston continues its stroke under the expansive force of the steam in the cylinder, and towards the end of the stroke raises the plunger of the cataract to prepare it to repeat its functions during the next indoor stroke. The horn or lever of the cataract being thus depressed whilst the steam valve is closed, the catch U falls under the influence of the weight of the lever M under the projection on the circumference of the quadrant K, thus preventing the opening of the steam valve when the steam tappets have been raised, during the up or *outdoor stroke* of the piston, above or clear of the steam horns, until the cataract weight shall have fallen sufficiently far to release the catch U, when the steam valve suddenly opens, as before described, and the next *indoor stroke* is commenced. Having described the functions of the steam or top arbor and tappets, we will consider next the equilibrium stroke. The middle is the equilibrium arbor, and the horn is shown in the side elevation. There are two quadrants on this arbor. The first G is released by means of a cataract constructed precisely like the one just described. The rod of this cataract is placed inside the gear posts, as shown on the front elevation, whereas that of the steam cataract is placed on the outside. There is an adjusting screw A on the equilibrium cataract rod, and two such, P, on that of the steam cataract. The lever C opens and closes the equilibrium valve. The opening is done by means of a counter-weight attached to the lever E, which operates on the release of the quadrant G. At the completion of the indoor stroke the piston pauses until the catch O, actuated by means of the cataract, releases the quadrant G. It will be seen that this cataract rod releases on its down stroke,

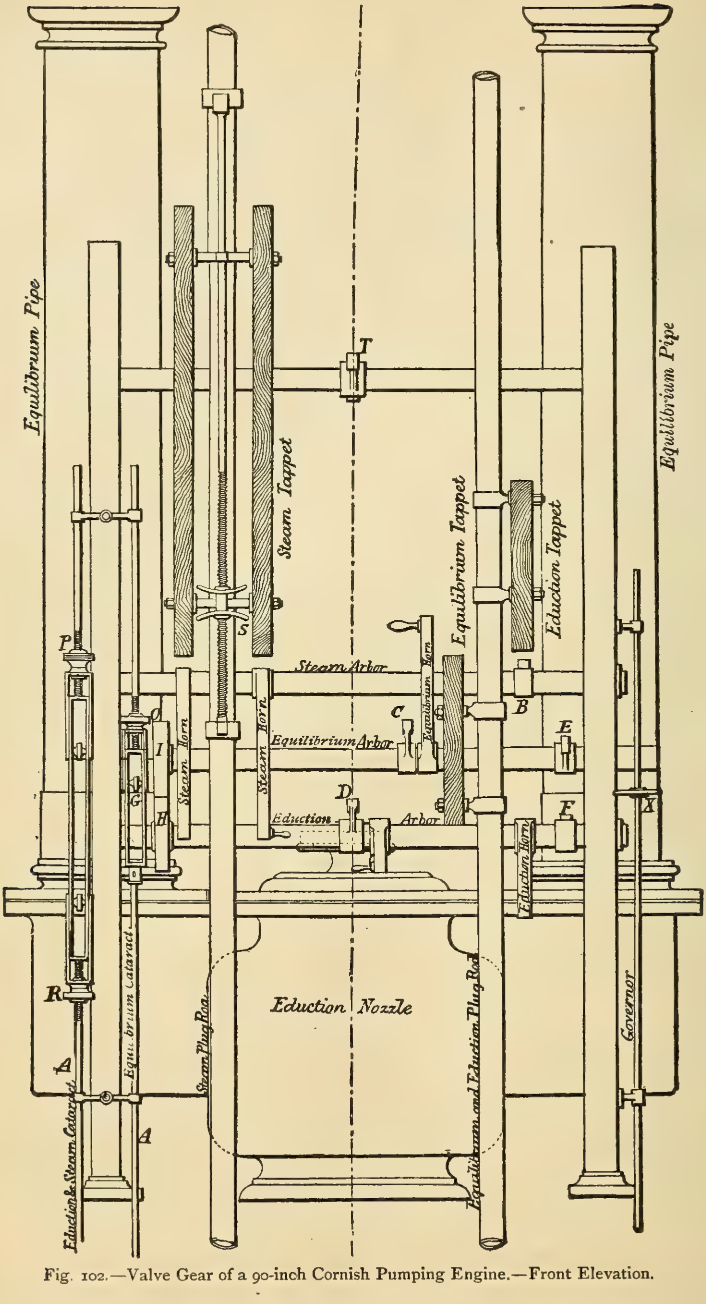


Fig. 102.—Valve Gear of a 90-inch Cornish Pumping Engine.—Front Elevation.

whereas the other does it on its up stroke. In the former case the rod

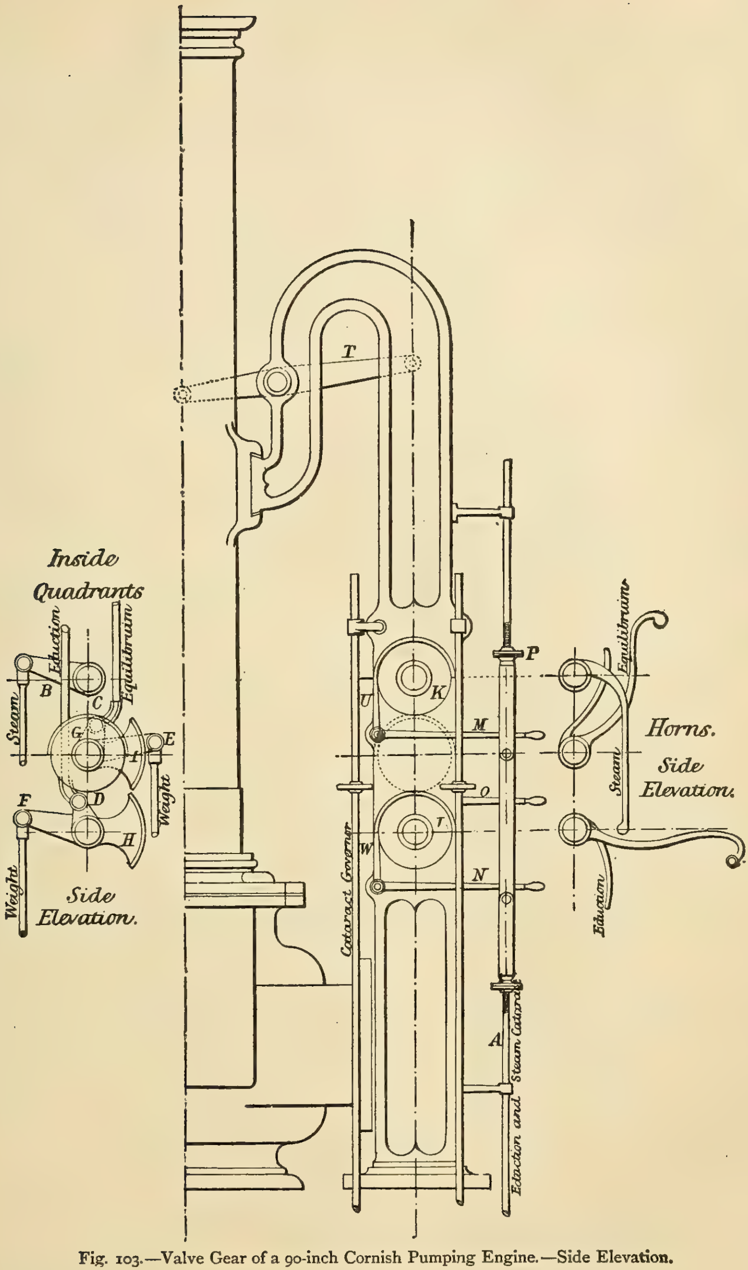


Fig. 103.—Valve Gear of a 90-inch Cornish Pumping Engine.—Side Elevation.

A is attached to the cataract lever on the same side of the fulcrum as

the plunger. The quadrant G being released, the equilibrium valve at the top of the cylinder suddenly opens, and a free communication is established between the top and bottom sides of the piston through the perpendicular or equilibrium pipes shown in outline on the woodcut. The *outdoor stroke* now commences; the piston, being in equilibrium, is raised by means of the weight of the pump rods and attachments, which is sufficient to force the water in the pumps and overcome all other resistances. During this stroke the plug rods move upward, and towards the end the equilibrium tappet comes in contact with the horn on the equilibrium arbor, and lifting it closes the valve, at the same time allowing the catch O to fall under the projection on the quadrant G. A portion of steam is thus confined in the top of the cylinder, which gradually brings the piston to rest, and prevents it striking the cover. The piston now pauses till the steam quadrant shall be released. The eduction stroke is performed simultaneously with the steam stroke. The eduction valve is situated in the bottom nozzle, and opens a passage to the condenser for the steam passed from the top to the under side of the piston during the equilibrium stroke. The lever D actuates the valve through the lever T. As the piston completes its *indoor stroke* the eduction tappet comes into contact with a horn on the eduction or lower arbor. The valve is opened by means of a counterweight at F, when the quadrant L is released by the cataract. The quadrants H and I are for the purpose of keeping the equilibrium valve closed until the closing of the eduction valve. It will be seen that, although the catch O may be released, the quadrant H prevents the opening of the equilibrium valve until the eduction valve is closed and the quadrant H brought into the position shown on the woodcut. It will be seen that if the catches M and N are released simultaneously the steam and eduction valves will open at the same time, but the times can be varied by means of the adjusting screws P and R. The hand wheel X is for the purpose of adjusting the amount of fall given to the weight which opens the steam valve, so as to give the valve a greater or less opening. The degree of expansion is varied on the plug rod by means of the screw S."[1]

The *cataract*, as a means of regulating the number of strokes of the Cornish pumping engine, is exceedingly simple. One arrangement consists of a wooden box, open at the top, fitted with another box internally, having flap valves at the bottom opening upwards,

[1] *The Engineer.*

as also a plug tap, which can be regulated at pleasure from the engine-room floor. There is a central rod secured through the bottom of this internal box or tray, and connected to a lever weighted at the end, with a fixed pin as the fulcrum, placed between the weight and the box; this weight is slightly in excess of the tray and adjuncts when the internal box is full of water. The action is as follows:—The outside box, in the first place, must be nearly full of water, and we will suppose the tray empty and raised by the weight acting through the oscillating lever; the plug rod of the engine descending acts on mechanism that depresses the tray, and water flows through the flap valves in the bottom until the plug rod ascends, when the preponderance of the weighted lever raises the internal box or tray above the level of the water in the outside box, consequently the water in the tray gravitates into the external reservoir—hence the name *cataract;* and the time the water takes to flow out of the one into the other is regulated by the plug tap,—if it is full open the water will flow out quickly, and the tray will rapidly ascend, the cataract rod releasing the valves; but should the plug tap be nearly closed, it is evident that the water will flow out of the tray slowly; and as this tap is regulated, the number of strokes of the engine will be increased or diminished: but the number of strokes rarely exceeds twelve per minute as the maximum, and four per minute as the minimum. This form of cataract is exceedingly simple, and even rude in construction, yet it answers the purpose admirably so long as the level of water is maintained in the external box, which must be looked to occasionally, as evaporation will take place or leakage occur.

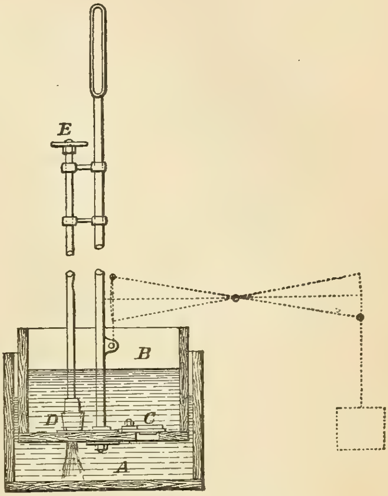


Fig. 104.—Cataract with Wooden Tray.

A, Box for water. B, Tray. C, Inlet valve. D, Regulating valve. E, Small hand wheel.

Instead of the wooden tray a plunger pump (Fig. 105) is sometimes fitted inside of a box of cast iron, having a valve at the bottom for admitting water or oil into the pump, fitted with a tap for regulating

the exit of the fluid. The weighted lever is so arranged that the plug rod lifts the plunger and weight, and the cataract rod for disengag-

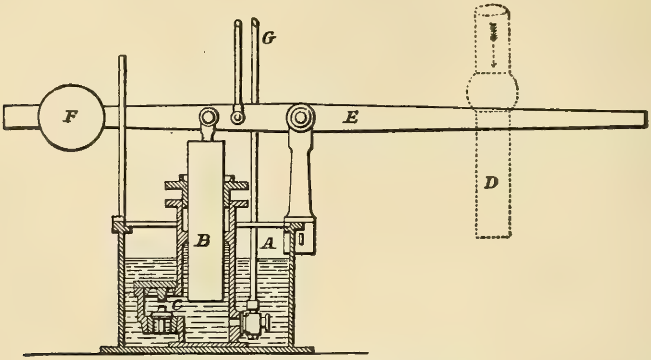


Fig. 105.—Cataract with Plunger Pump.

A, Cast-iron box. B, Plunger. C, Inlet valve. D, Plug rod. E, Lever. F, Weight. G, Regulating spindle and valve.

ing the valves ascends as the plunger and weight descend, the motion being changed by a lever; the cataract rod for lifting the paul is jointed at one end of the lever, and the rod passing down to the arm for the weight and plunger at the other end.

In some examples of the plunger type, when two cataracts are used, the plug-rod tappet acts on the two levers for lifting the plungers simultaneously; on the centre of motion of the levers a grooved wheel is fixed, and the lever for the cataract pump is connected by means of a chain wound round the wheels, and as the tappet or plug rod comes in contact with the levers the wheels are partially turned round, pulling one end of the cataract lever down, and raising the other end, to which the plunger and weight are fitted. Some arrangements of cataract pumps have a solid piston, or one fitted with cupped leather washers, and on the top of the piston rod a crosshead and side rods passing down under the floor of the engine house, and in communication with the mechanism for lifting the piston and weight placed on the top of the crosshead. A central metallic valve is placed at the bottom of the pump, and a tap is likewise fitted for regulating the ejection of the oil, which is generally used when the cataract is placed on the engine-room floor. This type of cataract has likewise a reservoir for receiving and supplying the oil; and as leakage past the piston ring occurs after being long in use, an air passage is formed above the piston in communication with the reservoir, and any oil passing the piston is

allowed to fall by gravitation into the cistern or metallic box. In another example, where refinement of construction is a desideratum, the cistern is dispensed with, and the oil is ejected through a valve fitted to the piston on the down stroke, and passes through the same valve on the up stroke, it being forced through by suitable mechanism in the down stroke, and the ascent of the piston is acted on by the weight, as in the former examples. This plan of cataract necessitates a hollow piston rod, with stuffing box on the pump cover, fitted with an internal rod attached to the valve, passing up to the crosshead, for taking the disengaging rod; this hollow rod is fitted with a stuffing box, and the internal rod has a thumb screw at the top for regulating the lift of the valve. Thus this valve allows of the oil passing from the bottom to the top of the piston, and also regulates the flow of the oil from the top of the piston to the under side of it, forming a self-contained and handsome cataract pump.

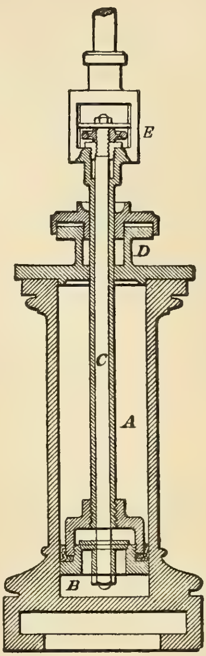


Fig. 106.—Cataract without Cistern.

A, Cylinder. B, Cupped leather piston with valve. C, Hollow rod. D, Stuffing box and gland. E, Thumb screw and gland.

The *condenser* (Fig. 107) for the Cornish engine is generally a separate vessel, worked on the injection principle. As the exhaust pipe from the steam cylinder is of large diameter and of considerable length, it is obvious that the cubical contents of the condenser need not be so large as for ordinary engines, the exhaust pipe acting as a receiver, and the steam being condensed in a vessel placed at the extreme end.

The *air pump* is of the ordinary kind, with metallic head and foot valves, the bucket being open, with a metallic valve placed on the top, and it is made tight with ordinary hemp packing plaited, or what is termed a gasket. In another example (Fig. 108) the air pump and condensing vessel are placed inside of a cast-iron tank, which is kept constantly full by means of a pump termed the cold-water pump. When this arrangement is adopted the condensing vessel is kept quite cool by the surrounding water, and to a certain extent acts as a surface condenser, in combination with the injection system. The tank

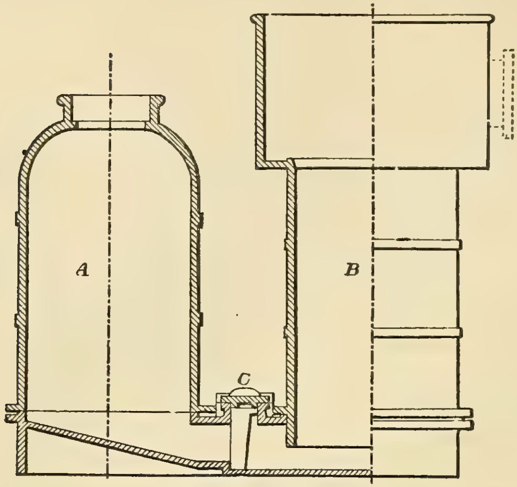


Fig. 107.—Condenser and Air Pump, with Foot-valve Seating.
A, Condenser. B, Air pump. C, Foot-valve chest.

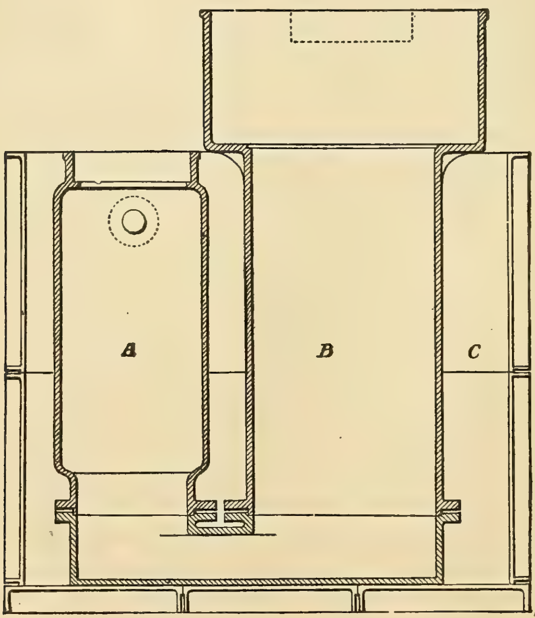


Fig. 108.—Air Pump and Condenser without Foot Valve contained in a cast-iron Tank.
A, Condenser. B, Air pump. C, Tank.

must be fitted with an overflow pipe, which is placed in communication with the discharge from the air pump. When the water is very bad the air pump should be lined with a barrel of composition metal, or a brass barrel is so placed, centrally with the condenser; and when suitably strengthened and supported from the condenser vessel, the latter proves a very compact arrangement, combining the condenser and air pump in one. The foot valve, in ordinary arrangements, is placed at the bottom, between the condenser and air pump. It is a flap valve hinged vertically, and is sometimes made of wrought iron, faced with a brass beating surface, with a corresponding brass face securely pinned on the cast-iron seat. The valve is bent to form a hooked hinge, so that it can be readily taken off the spindle on which it hinges without disturbing the seat, a door being fitted to the condenser casting for inspecting

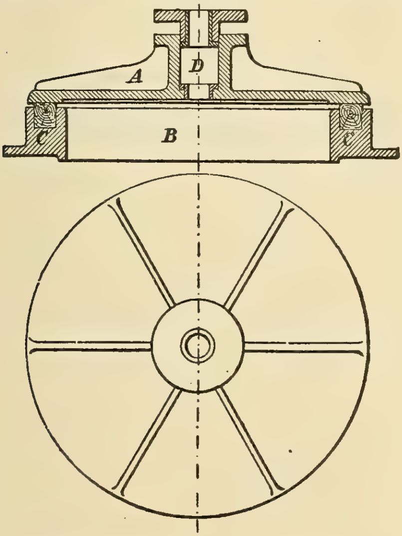


Fig. 109.—Head Valve with Wooden Beat on Seat.

A, Valve. B, Seat. C C, Wooden beat. D, Stuffing box and gland.

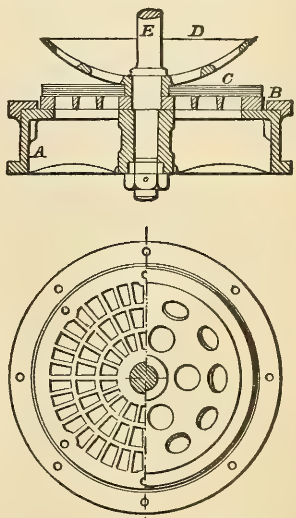


Fig. 110.—Air-pump Bucket, with Brass Seat for India-rubber Valve.

A, Bucket. B, Brass seat for valve. C, India-rubber disc. D, Guard. E, Rod secured with a nut at the bottom.

and adjusting the valve. The head valve, placed at the top of the air pump, is a disc of metal having a deep boss at its centre, strengthened with ribs radiating from the centre, and having a hole bored through the boss for receiving the air-pump rod, which acts as a guide for the valve. Sometimes this boss is fitted with a gland

and packing space, thus making it perfectly water-tight. The seat in this example is cast separate, and bolted to the air-pump, and fitted with a ring of wood for the valve to beat against. The valve fitted to the top of the air-pump bucket is of a similar description, with a plain hole lined with brass, which acts as a guide. In some cases the valve on the bucket (Fig. 110) is of india rubber, working on a grating of brass bolted to the bucket. The air-pump bucket is fitted with a junk ring and packing space, and when a brass barrel is used may be packed with hemp, or a metallic, or even wood packing will be found to answer. Thin metallic rings sprung into recesses make a first-class packing, and last much longer than hemp.

The Ejector Condenser.—In the ejector condenser the air pump is entirely dispensed with. The principle of the apparatus may be described as follows:—In every injection condenser the cold water rushes into the vacuum with a velocity of about 43 to 44 feet per second; while the exhaust steam from the cylinder of the engine, at the pressure of 10 lbs. per square inch below the atmosphere, rushes into the condenser with a velocity of about 1200 feet per second, when a vacuum of 25 inches of mercury is maintained. In the common condenser these rapid motions of the water and the steam are completely checked, and their energy is wasted, and hence an air pump is imperative, so as to extract the water, air, and condensed steam from the condenser. In the ejector condenser the exhaust steam from the cylinder of the engine after each stroke is so directed through a discharge nozzle as to unite in a jet with the condensing water, by which it is itself condensed, having, however, imparted a sufficient velocity to the combined jet to enable it to issue directly into the atmosphere in a continuous yet impulsive stream. The contents of the condenser, both water and air, are thus ejected without the use of an air pump, and at the same time without impairing the vacuum in the condenser. This result is obtained, however low the pressure may be to which the steam is expanded before the exhaust from the cylinder takes place, if the injection water be supplied with a few feet of head pressure: and the effect is produced by taking advantage of the high velocity at which the exhaust steam and the injection water flow into a vacuum. The ejector condenser not only discharges the products of condensation into the atmosphere from a pressure of 12 lbs. per square inch below the atmosphere, but with a steam pressure equal to the atmosphere at the

commencement of the exhaust, the condenser, when applied to a pair of coupled engines, is found capable of lifting the condensing water from a lower level of 6 to 8 feet, or raising the discharged water to a proportionate height above the condenser.

In the simplest arrangement the injection water enters the condenser in the form of a central jet through the conoidal nozzle A, which is supplied by the branch pipe B; and the area of the orifice is regulated by an adjustable central spindle C, which is raised and lowered by an external screw and hand wheel. The exhaust steam entering at the branch pipe D, passes through the annular space surrounding the central water jet, and the combined current passes on through the fixed conoidal nozzle F, into the discharge tube G leading to the hot well. This tube is trumpet-mouthed, so as gradually to diminish the velocity of the current as it passes through, and utilize its moving force by avoiding useless velocity at the point of discharge, the enlargement of the tube increasing more rapidly towards its outer extremity.

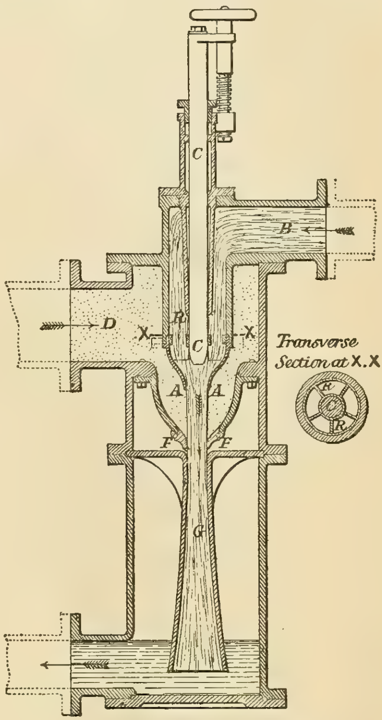


Fig. 111.—Condenser supplied with Head of Injection Water.

In starting the condenser the centre spindle is raised by means of the hand wheel, and a jet of injection water is discharged through the centre of the current of the exhaust steam from the engine: the injection water being in this case supplied from a head of water a few feet above the condenser, so as to flow into it by gravity. The condensation of the steam by contact with the injection jet produces a vacuum within the condenser, and the water then enters with the velocity due to the difference of pressure between the external atmosphere and the degree of vacuum maintained in the condenser, added to the velocity due to the head of water in the injection supply. The water jet having a straight passage for

its exit, without any obstruction, retains its initial velocity, and rushes on through the combining nozzle F and the expanding discharge tube G, and issues into the atmosphere in a continuous stream, carrying with it any air mixed with the exhaust steam, the action being somewhat similar to that of the injector for feeding boilers.

It is requisite for the injection water to enter the combining nozzle in a straight stream, without any eddy or rotation of the water; and whenever the injection is supplied with the pressure of a head of 10 feet or upwards, a provision is made for stopping any rotation of the stream, by inserting within the nozzle a guiding piece R, with several straight radial vanes, as shown in Fig. 111.

The proportion that has been found most effective for the injection jet is for the length of the free portion of the jet, which is exposed to the action of the exhaust steam, to be about three times the diameter of the jet, except when the injection water is supplied with a head of 10 feet and upwards, in which case the length of the exposed jet is increased with advantage to 3½ diameters.

The moving force in the current of the exhaust steam rushing into the condenser communicates an additional velocity to the water jet on issuing from the water nozzle, the amount of this addition being dependent upon the difference of pressure between the exhaust steam and the condenser; and when the steam is not expanded down in the cylinder of the engine to a very low pressure before its exhaust, the combined moving force in the water jet is found to be sufficient to effect a continuous discharge into the atmosphere, not only without aid from a head of water in the injection supply, but leaving a surplus power sufficient for raising the injection water from a lower level of several feet below the condenser. When the injection water is not supplied by a head pressure, but has to be raised from a lower level, the working of the condenser (Fig. 112) is started in the first instance by means of a jet of steam direct from the boiler, introduced through the central spindle C, so as to act in the axis of the water jet. The steam is admitted to this jet through the small piston valve J, which has a second piston valve I, fixed below on the same spindle. This lower piston is supported by a spiral spring, and communicates with the condenser on the under side by the pipe H; and as soon as a vacuum is formed in the condenser, the piston valve is moved, the pressure of the atmosphere acting on the top of the upper piston J causing this piston to shut

off the steam jet. In the event of the vacuum ever becoming impaired from any cause, the piston valve is instantly raised by the pressure of the spring below it, and a jet of steam from the boiler is thus applied by self-acting means to the extent that may be required for restoring the full action of the condenser.

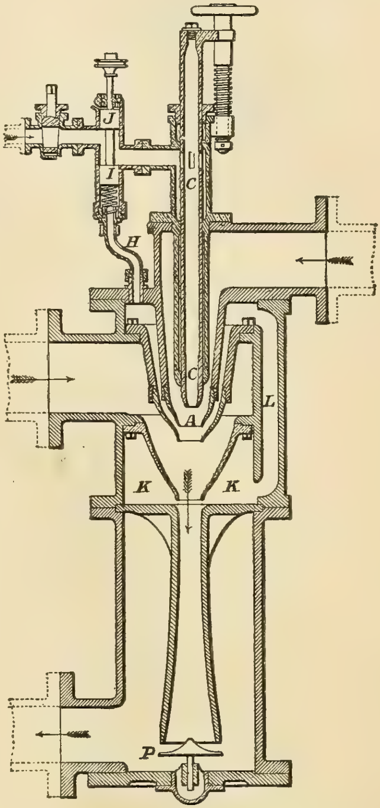


Fig. 112.—Condenser with Self-adjusting Jet of Steam.

When the piston of the engine makes only a few strokes per minute, the impulse received from the successive discharges of the exhaust steam fluctuates, a portion of the water fails to get the full velocity of discharge imparted to it, and escapes at the nozzle into the chamber K. This overflow water is removed continuously by means of the side return passage L, which communicates with an annular space surrounding the water nozzle A, and the water is carried forward by being brought again into contact with the jet of exhaust steam.

In another form (Fig. 113) the condenser is shown as applied to a pair of engines coupled at right angles; the only alteration being the addition of a second combining nozzle N, fixed beyond the first one, and communicating with a second branch pipe M, which brings the exhaust from the other cylinder of the coupled engines. The first nozzle F so completely separates the two steam jets from each other that the alternate discharge of the exhaust steam from either cylinder cannot in any way impair the vacuum in the other cylinder: the degree of vacuum is found in some cases to be rather higher in the upper nozzle than in the lower one, the steam in the upper nozzle being the first to come in contact with the injection water. In this arrangement, as well as in the preceding one, a foot valve P

is provided at the exit orifice of the discharge tube to prevent any inflow of water from the hot well into the condenser, when the vacuum ceases when the engine is stopped.

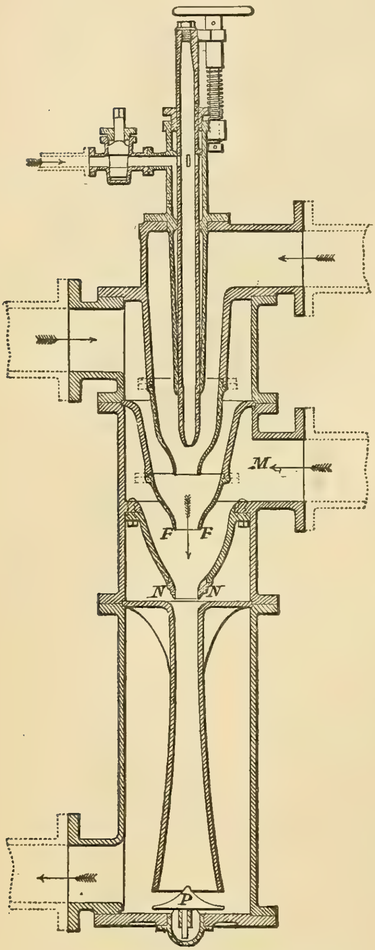


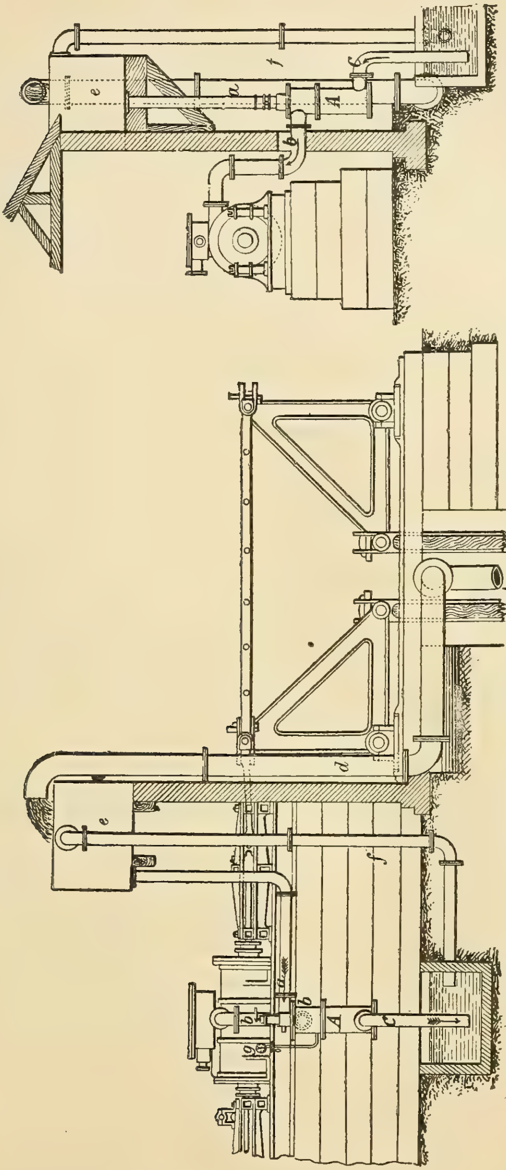
Fig. 113.—Condenser for a pair of Coupled Engines.

Mr. Alex. Morton of Glasgow informs us that he has fitted these condensers to all classes of land engines, from the slow-going pumping engine making three revolutions per minute, to other engines having a piston speed of 500 feet per minute, and even engines having a greater piston speed than this have been fitted with ejector condensers.

We give side and end views of an ordinary horizontal pumping engine (Figs. 114, 115) fitted with the condensing apparatus. The condenser is placed below the level of the steam cylinder of the engine, and may be in any convenient position either inside or outside of the engine house. The rising main from the pit pumps delivers the water into a tank a few feet above the level of the condenser; having a pipe for supplying the injection water to the condenser, and the discharge from the condenser passes through a pipe into a drain, as shown.

In another example of blowing engine at an iron-works near Bridgend in Glamorganshire, the cylinder being 40 inches diameter and 10 feet stroke of the piston, making fifteen revolutions per minute, the condensing apparatus maintains a constant and steady vacuum of 12½ lbs. below the atmosphere. The injection water in this case is supplied from a head of 1½ foot above the condenser, and the discharged water has a fall of about 9 feet, consequently no starting jet is required in such cases.

The *cold-water pump* is a cast-iron barrel, fitted at the bottom



Figs. 114, 115.—Ejector Condenser fitted to a Horizontal Pumping Engine. Side and End Elevations.

A, Ejector condenser. *a*, Injection pipe. *b*, Exhaust-steam pipe. *c*, Pipe from hot well. *d*, Pipe from pit pump. *e*, Cistern. *f*, Overflow pipe. *g*, Vacuum gauge.

with a suction valve of the flap type, consisting of a disc of leather securely fastened down with a bar of iron to the conical valve seat,

and arranged with a central feather, the disc being fitted with wrought-iron plates on the top and bottom, securely rivetted through and through. The bucket is fitted with a valve of a similar description, having means of securing it to the pump rod; and it is usually packed with a plain hemp gasket let into the recess formed in the bucket, and fastened by means of plain wooden pins driven through holes bored in the side. Some consider, however, that these buckets should be fitted with gutta-percha rings, let into recesses formed on the bucket, with holes bored from the top in connection with the recesses; thus when the gutta-percha rings are cut and sprung into the recesses, the head of water acts on the inside of the rings, keeping them up to the face.

The *feed pump* is of the ordinary plunger type, fitted with metallic valves, and draws the water from the hot well above the air pump, the water being partially heated by the steam in the process of condensation. All these pumps are generally worked from rods directly fastened to the engine beam, on the opposite end from that of the steam cylinder. The rod for the air pump is generally placed midway between the main centre and the end of the beam; the cold-water pump rod is situated between the air-pump rod and the end of the beam; while the feed-pump rod has a shorter stroke than either, being placed between the air pump and the main centre on which the beam vibrates.

The beam is generally shorter on the pump end, the steam piston having a longer stroke; thus the motion of the main plungers or buckets, if so fitted, is slower than that of the steam piston, and this diminution of velocity decreases the wear and tear of the pump gear. Moreover, increased length of piston stroke requires less diameter of cylinder, which is a great desideratum when high steam pressure with a large measure of expansion is used, as the parts need not in this case be made so heavy. Some makers have introduced a small high-pressure cylinder in combination with a larger one; the steam in the first place acts on the small piston, and then expands into the large cylinder. The large cylinder and its adjuncts need not therefore be so heavy as with the single-cylinder arrangement, but it is obvious that greater complication is entailed, and for economy of fuel the single cylinder with a long piston stroke is to be preferred. Cornish engineers endeavour to economize fuel by a careful clothing of the parts where radiation takes place. The cylinder is inclosed in a steam jacket, as already described; the

outside cylinder or casing is covered over with felt or non-conducting material, and then carefully lagged with wood, with four or more metallic straps girding it all round; in some instances heated air has been applied all round the steam cylinder, the annular space being encircled with brick-work. The thorough protection of the inside or working cylinder so as to prevent surface condensation, and the covering of the steam pipes from the boiler with felt and canvas to prevent radiation—combined with the high steam pressure used and the large measure of expansion obtained—have raised the duty performed by the Cornish engine far above that of the ordinary class of engine used for land purposes.

Figs. 116 and 117 give side and end elevations of an overhead-beam pumping engine erected at a pit near Kilmarnock. The principal advantage in the arrangement here is that it leaves the pit mouth clear, and in sinking a pit enables the rods to be easily lengthened as required.

The cylinder is 84 inches in diameter, suited for a 12-feet stroke in the pump. The piston rod is connected to a strong malleable-iron beam, made of two plates placed 15 inches apart. The pump rod is connected to one end of the beam, and the other end is supported by vibrating columns oscillating on journals working in two bearings, which are bedded on the top of the stone pedestals for the foundation, and secured with bolts and nuts passing down through the foundation, and having a cotter and wall plate at the bottom.

The parallel motion for the piston rod consists of two motion rods, one on each side of the beam, connected to cast-iron standards bolted to projecting flanges on the top of the cylinder. The plug rod for the valve mechanism is worked directly off the beam, from the same gudgeon as for the parallel-motion bars, and is guided with a bracket placed underneath the engine-room floor.

The engine is fitted with a blow-through condenser, on a plan which works as follows:—Steam being admitted to the bottom of the cylinder, the piston is forced to the top of its stroke; the steam valve is then shut by suitable gearing, and the steam passes from the bottom side of the cylinder to the top side, the piston is then in equilibrium, and the weight of the pump rods carries it to the bottom, but before it reaches this point the injector valve is opened with a tappet placed on the feed-pump rod, with levers and rod carried along to the valve; water is thus admitted into the condenser, and the valve remains open until the steam is

shut off, and the piston nearly at the end of the up stroke; the remaining exhaust steam in the top blows the water and condensed

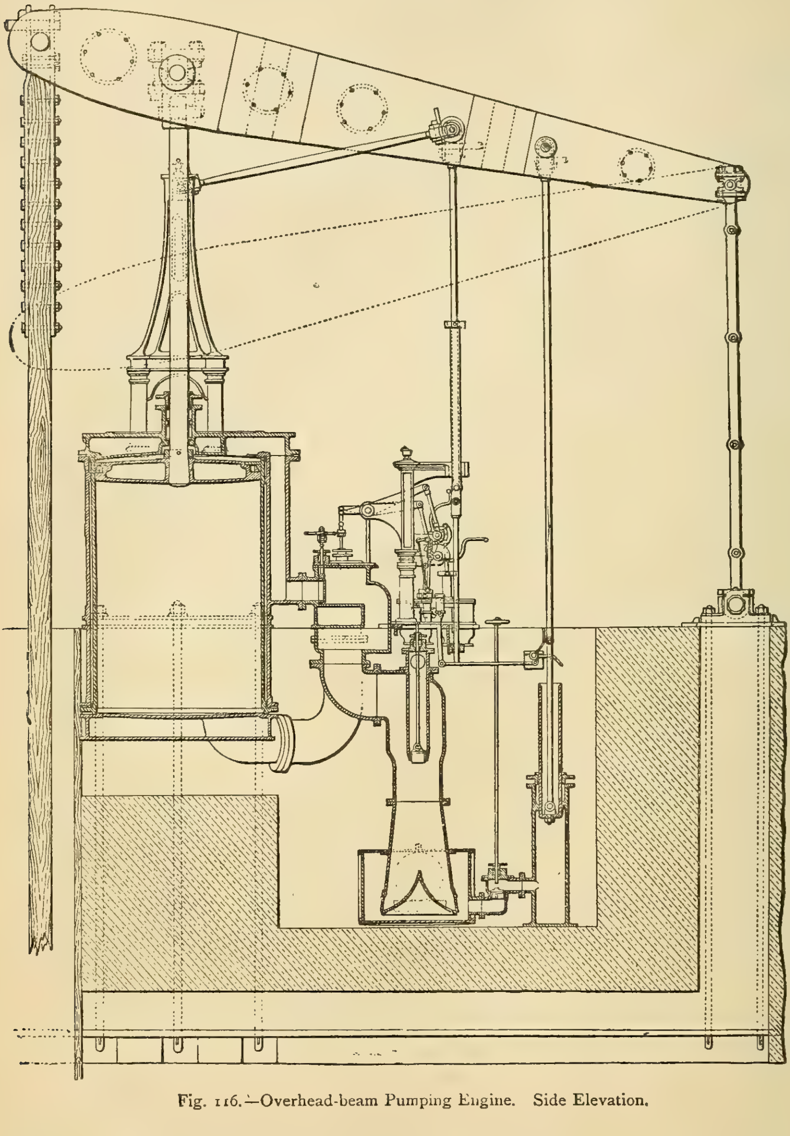


Fig. 116.—Overhead-beam Pumping Engine. Side Elevation.

steam out of the blow-through valves at the bottom of the condenser into the overflow cistern, from which it is led into a drain. In working, the water in the condenser rises to nearly the level of the

injection valve. Besides the ordinary steam and exhaust valves, there is a valve worked by hand for regulating the descent of the

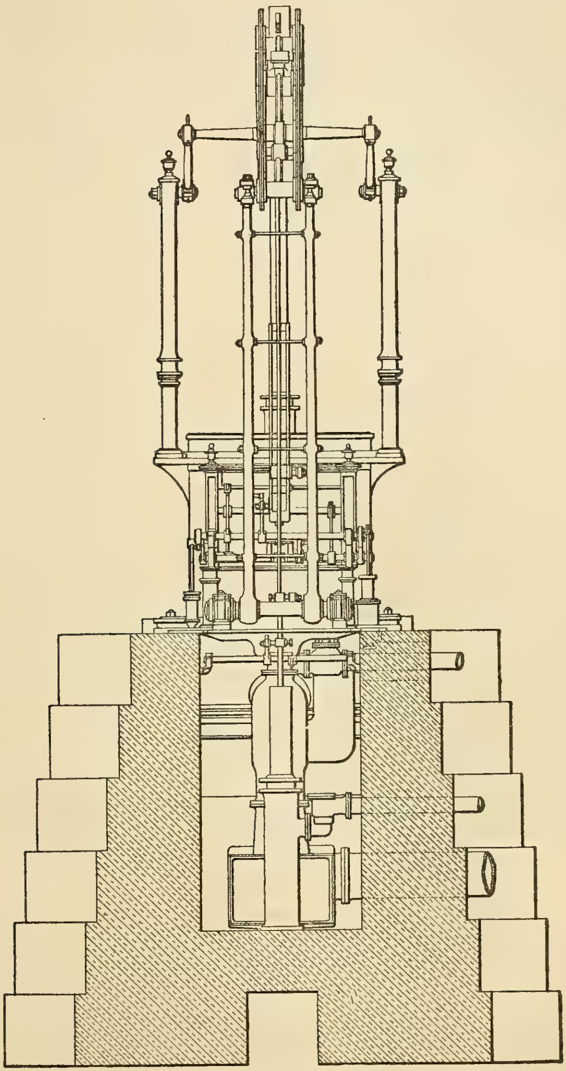


Fig. 117.—Overhead-beam Pumping Engine. End Elevation.

piston, and placed at the bottom of the passage leading to the top of the cylinder. The feed pump is of the plunger type, worked directly off the overhead beam; the suction valve is placed at the

bottom of the barrel, and the delivery valve at the top. The annular space round the plunger is equal to the area of the plunger. With this arrangement no air can collect at the under side of the gland, as when the delivery valve is placed at the bottom of the barrel.

The main pump for this engine is of the plunger type, the rods being cottered to the plunger, instead of the wooden rod passing

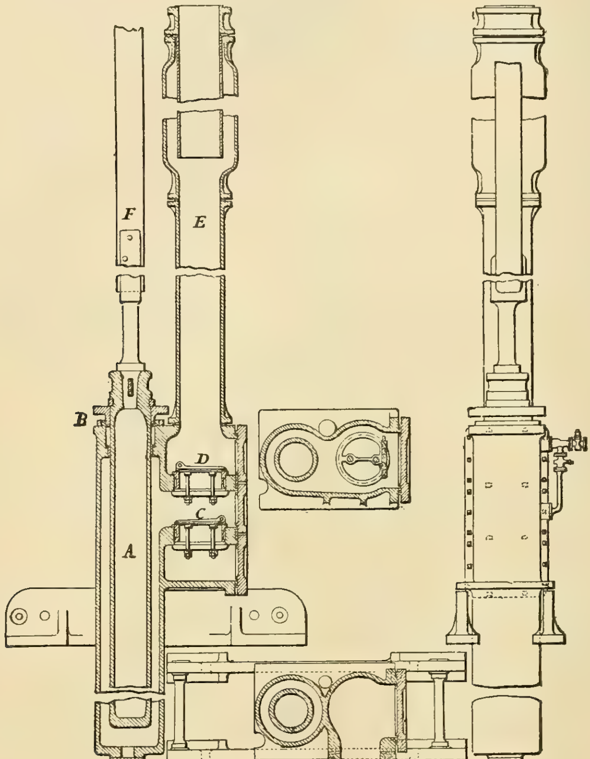


Fig. 118.—Pump.

A, Plunger. B, Stuffing box and gland. C, Suction valve. D, Delivery valve. E, Stand pipe with air vessel. F Pump rod.

down through it, as has been already explained. The diameter of the plunger is 18 inches, with an annular space all round equal to the area of the rams. The suction and delivery valves, of the flap type, are placed at the top of the pump barrel—this arrangement getting rid of the air that collects in a barrel having the valves arranged at the bottom. On the stand pipe an air vessel is fitted, to relieve the shock on the ram in the act of forcing the water. This arrangement of

pump necessitates the use of a separate suction pipe, which is fitted to the side of the valve chest placed underneath the suction valve.

Side-lever engines have been introduced with the object of reducing the great height of the massive lever wall for carrying the

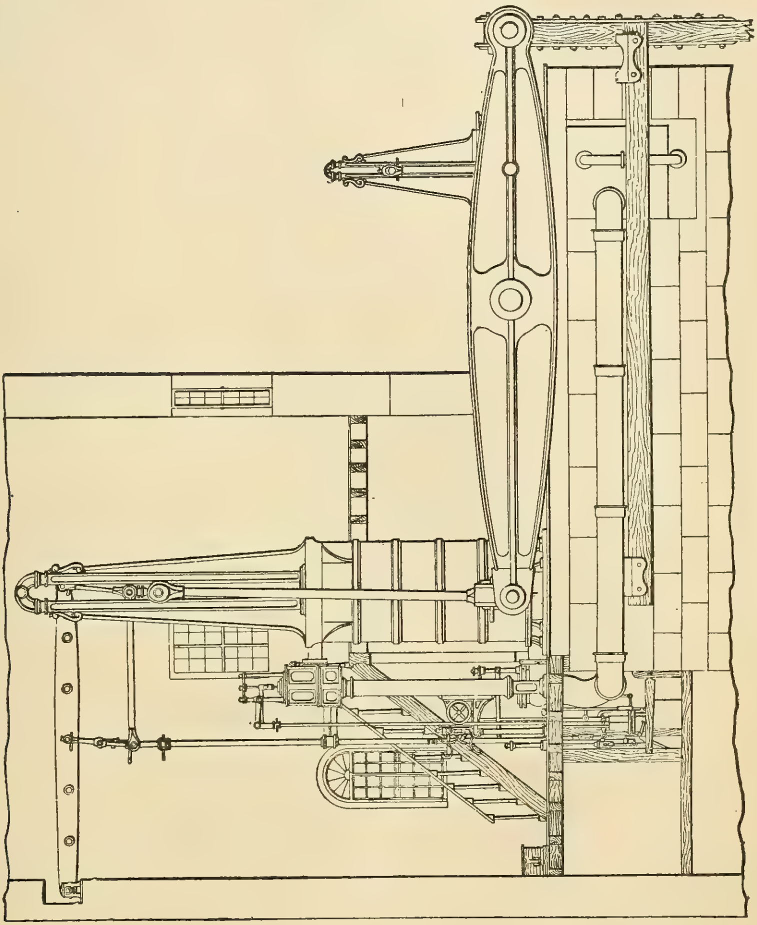


Fig. 119.—Side-lever Pumping Engine.

main beam, and of simplifying the engine by dispensing with the expensive parallel motion. The arrangement possesses certain advantages; the main one being that the engine is self-contained, having a bed plate for carrying the cylinder, main pillow blocks, condenser, air pump, &c. The side levers are connected to the piston rod by means of side rods, and a crosshead working in cast-iron guide frames; the expense of keeping in repair those guides, in

comparison with the numerous brasses of the parallel motion, is very trifling. The air pump is worked in a similar manner, while the plug rod is actuated with a separate wrought-iron beam, placed above the main crosshead, and worked therefrom by means of a small crosshead, fitted to the top of the piston rod with a parallel motion—an unnecessary refinement, as when the plug rod is guided at the top and bottom a plain link attachment is all that is needed.

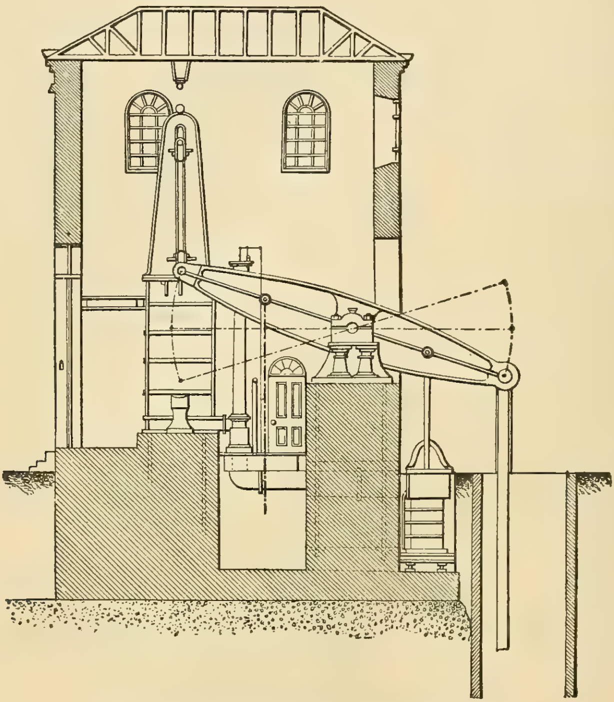


Fig. 120.—Single-acting Side-lever Pumping Engine.

The other end of this beam vibrates on a gudgeon, with pillow blocks resting on the end wall of the engine-house. The spring beams of wood are placed on each side of the foundation, these springs being necessary to check the shock should the engine miss a stroke or come in or out too rapidly—the ends of the side levers, striking against the spring beams, greatly reduce the blow, which would otherwise be felt very severely on the machinery.

There is another example of the side-lever pumping engine, Fig. 120, which although not possessing the advantage of being securely

bedded on a base plate, yet reduces the height of the lever wall considerably, while its arrangement is somewhat simpler than in the foregoing example. The valve gear is placed between the cylinder and the main centre of the side levers; thus the additional beam for working the plug rod is dispensed with, the rod being worked directly from a cross gudgeon between the two side levers; this gudgeon has an elongated hole for the rod to pass through, and is fitted with two side links connected to a crosshead on the plug rod, the rod being guided through bushes at the top and bottom. All the other pumps are worked directly from a gudgeon placed between the side levers, and securely keyed to them; but the main pump gudgeon has a bearing at each end, working on turned bushes on the under side. This gudgeon is made flat in the body, being deeper at the middle, and the pump rods of wood are securely fastened to it by means of wrought-iron straps, the great length of the pump rods causing them to bend with the versed sine described by the side levers. The pillow blocks for carrying the side levers are provided with a broad base plate, securely bolted down to the lever wall; the caps for the pillow blocks are simply shells, fitted for the sake of appearance, as indeed are all the covers for the pillow blocks of Cornish engines when adapted for mining purposes. This arrangement is adopted owing to the steam acting on the top of the piston at one end of the beam, while the great weight of the pump rods is being lifted at its other end; and in the outgoing stroke, or descent of the pump rods, the steam pressure on the top of the piston is in excess of the under side, and consequently the side levers have no tendency to lift.

Some mine-pumping engines have been erected on the direct-action principle, the steam cylinder being placed directly over the pumping shaft, with the pump rods attached directly to the piston rod, the steam acting on the under side of the piston. There is no equilibrium valve fitted to this class, as the steam, after doing duty in lifting the pump rods, is exhausted into the condenser, which is in connection with the top of the cylinder, and the downward motion of the pump rods is retarded. The weight of these rods is always in excess of what is required for forcing the water, and is due to the diameter of the pump and the great length of the rods. Of course the steam in the cylinder can be throttled in its passage to the condenser, thus gradually reducing the pressure and preventing the pump rods descending too rapidly. The air pump is worked

by a vibrating lever, linked to the piston rod, and placed underneath

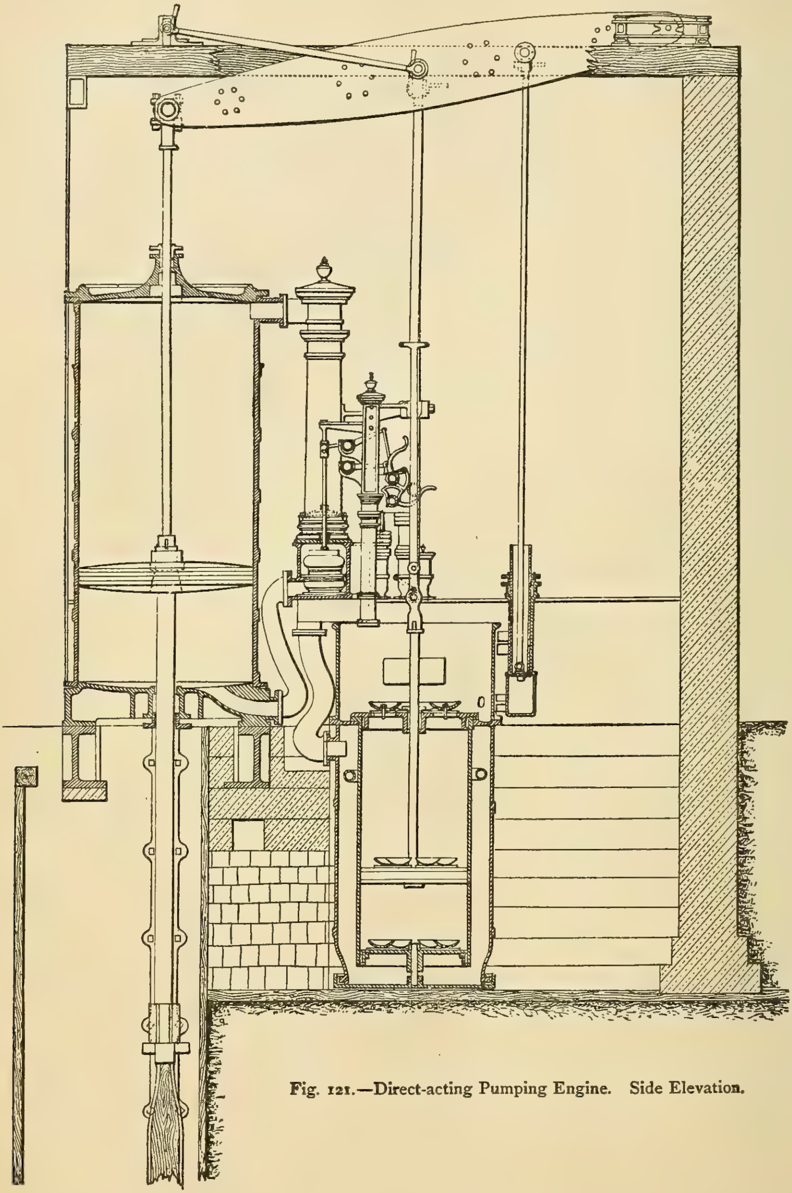


Fig. 121.—Direct-acting Pumping Engine. Side Elevation.

the cylinder floor; the motion of the lever working the plug rod for the valve mechanism. This class of engine, modified, has come

into extensive use, and, although cheaper in first cost, we unhesi-

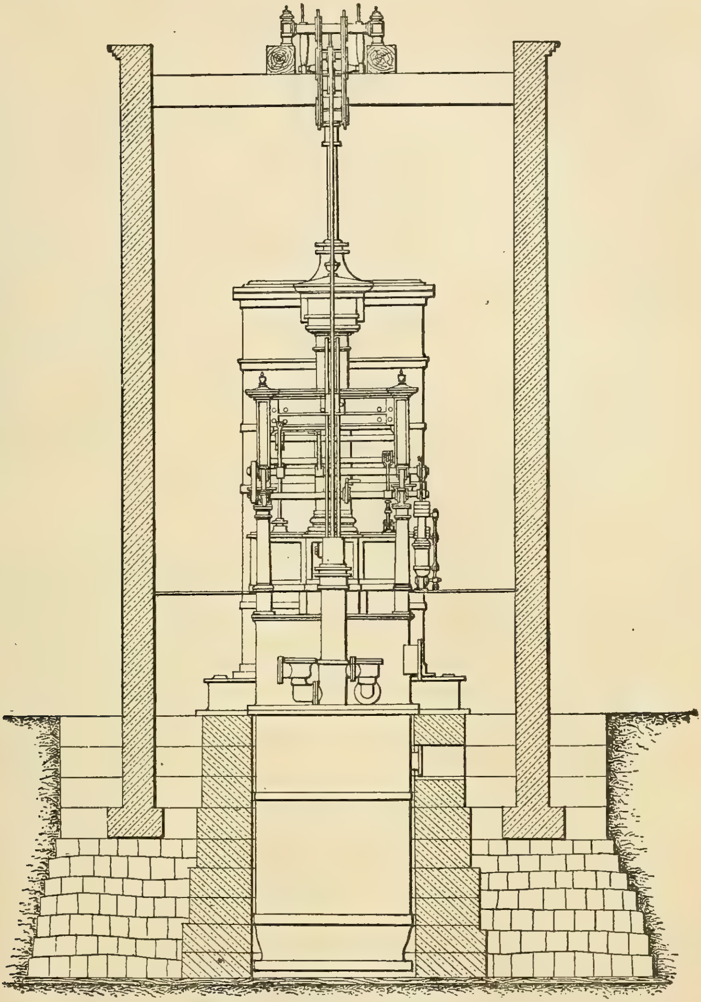


Fig. 122.—Direct-acting Pumping Engine. End Elevation.

tatingly give the preference to the beam engine, or the more recent example the side-lever Cornish engine, when the depth of the mine is considerable.

Figs. 121 and 122 show side and end elevations of a pit engine which may be considered an improvement on the foregoing example. The steam cylinder has a diameter of 84 inches,

suited for a 13-feet stroke. The pump rods are connected directly to the piston rod, which is guided by means of a crosshead and cast-iron guides placed underneath the cylinder. The light wrought-iron beam for working the plug rod, air pump, and feed pump is placed overhead, and is worked from a continuation of the piston rod. The vertical motion of the plug rod is maintained by means of motion rods fitted on each side of the beam, and is guided with a bracket bolted to the nozzle chest; the other end of the beam slides in cast-iron guide bars, with gudgeon and sliding blocks fitted to it. The air pump is placed centrally with the condenser, and is worked off a continuation of the plug rod; the air-pump bucket foot and head valves are fitted with small disc india-rubber valves, with guards secured by a single stud bolt in each. The feed pump has a hollow plunger, and is worked off the overhead beam directly, the pump being bolted to the side of the hot well. This engine goes far to meet the requirements of the practical miner, being well arranged, with easy access to all the parts; and it is much cheaper in first cost than some other beam engines.

The pumps for this engine consist of two lifting sets 20 inches in diameter, and one forcing set 26 inches in diameter, placed one above the other, as shown in Fig. 123. In deep pits this plan is always adopted, the lifting sets placed at the bottom of the pit discharging into a cistern from which the forcing set draws its supply. By this means the bucket and clack of the lifting set can be withdrawn and replaced should anything go wrong, and the water rise above the valve chests, which could not be done were the forcing set placed at the bottom of the pit. The pump valves are of the ordinary description, with inclined seatings; the plunger of the forcing set has just the necessary clearance in the barrel, the valve chests being arranged at the bottom; the water is discharged into an air vessel surrounding the stand pipe, by which means the shock in forcing it up is greatly softened.

For very deep pits a series of lifts is necessary. The following example (Figs. 124 and 125) of pit work in Cornwall forms a good arrangement: "The diameter of the steam cylinder is 90 inches. The stroke is 11 in and 10 out, in miners' parlance; that is to say, 11 feet in the cylinder and 10 feet in the pumps. The first lift of pumps from surface, or 'grass,' is the house lift, which is employed in lifting water from the adit to the condensing cistern of the engine. The plunger of this lift is 12 inches in diameter, and the rising main the

same size; it is usual to make the 'pumps' or rising main the same size as the plunger. The adit is 31 fathoms below the surface, and

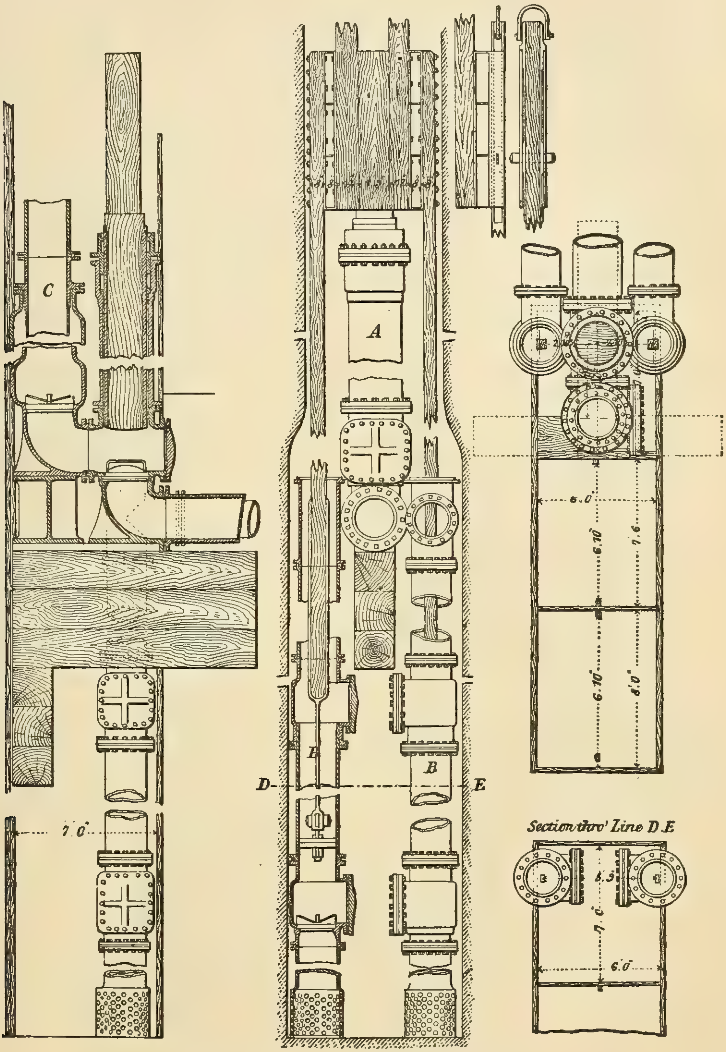


Fig. 123.—Pumps for Direct-acting Engine.

A, Forcing set. B B, Lifting sets. C, Stand pipe with air vessel.

conducts the water delivered from the pumps into the adjoining valley. Of course it is an advantage to have the adit as deep as possible, that the engine may have the minimum amount of work

to do. The second lift is situated 47 fathoms under the adit, and is provided with two suction and two delivery clacks. The third lift is 80 fathoms under adit; the fourth 120 fathoms, and the drawing lift 140 fathoms. It is not advisable to put in a lift of pumps

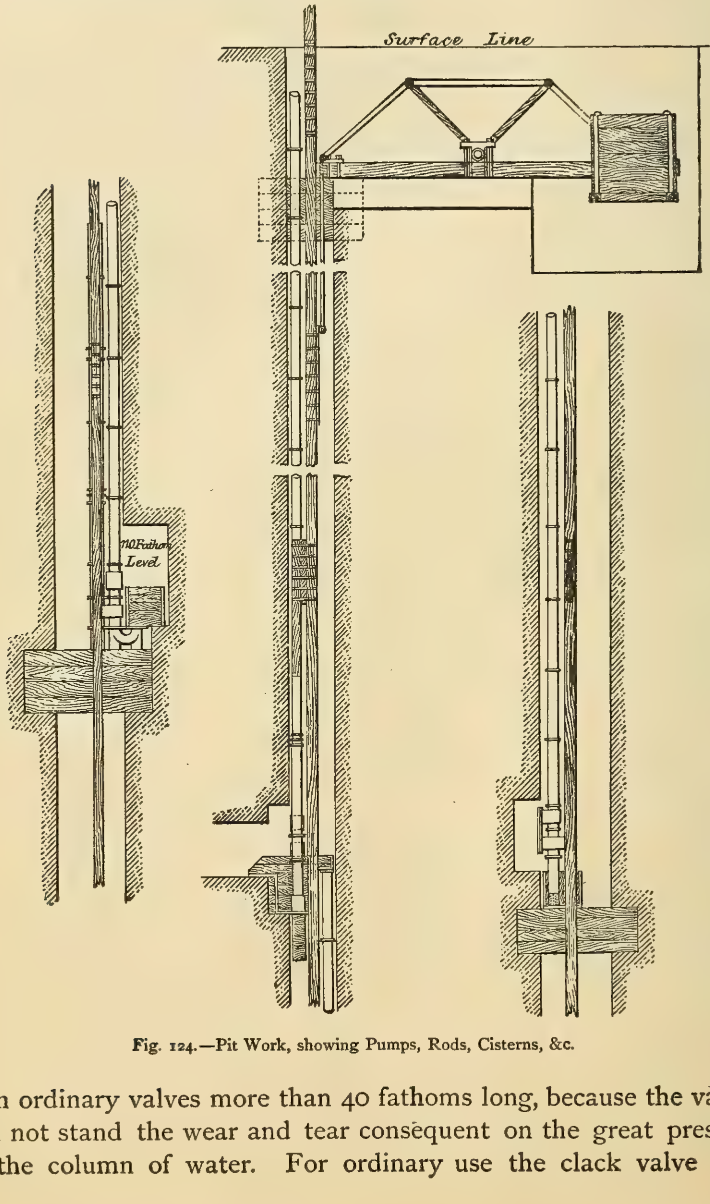


Fig. 124.—Pit Work, showing Pumps, Rods, Cisterns, &c.

with ordinary valves more than 40 fathoms long, because the valves will not stand the wear and tear consequent on the great pressure of the column of water. For ordinary use the clack valve with

leather seats enjoys the greatest favour in Cornwall. The pole case, that is, the case into which the plunger enters, is placed on one leg of what is termed the H-piece. The H-piece is provided with a

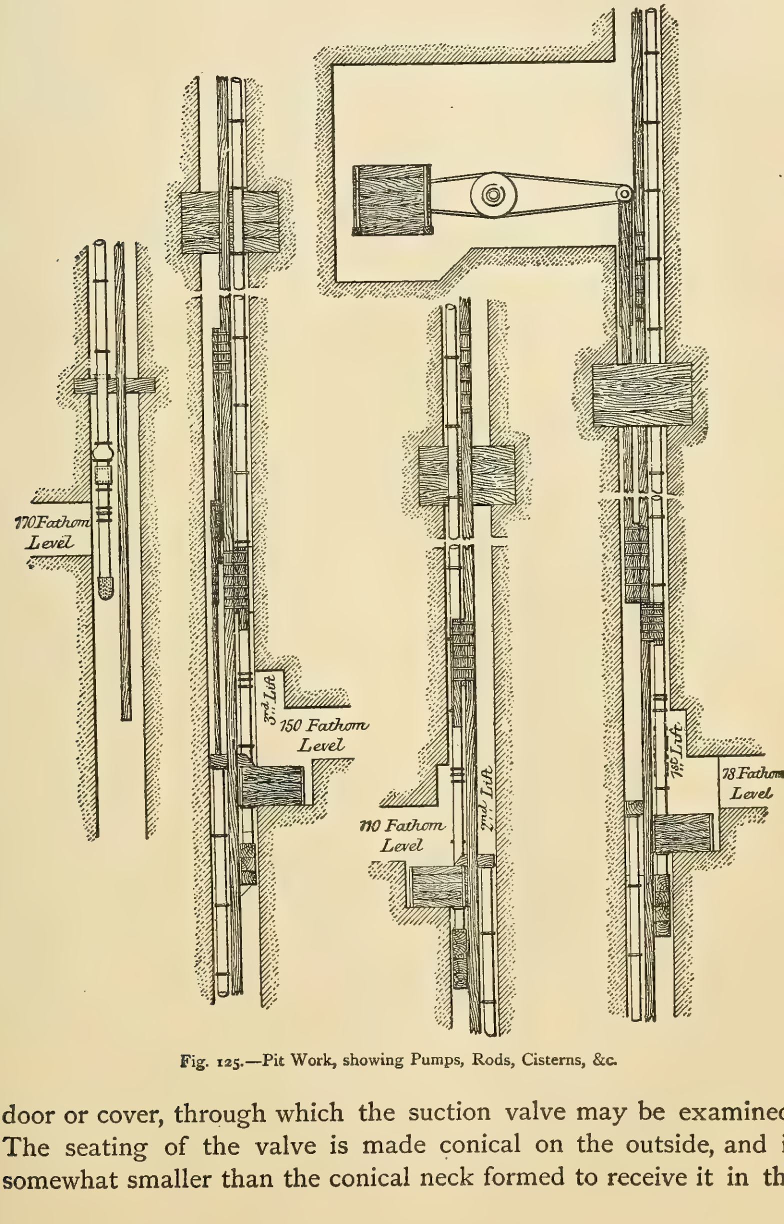


Fig. 125.—Pit Work, showing Pumps, Rods, Cisterns, &c.

door or cover, through which the suction valve may be examined. The seating of the valve is made conical on the outside, and is somewhat smaller than the conical neck formed to receive it in the

H-piece. Around the seating is wrapped a strip of coarse flannel or baize, which makes the joint when the seating is forced into its place. Above the door of the H-piece is placed the door piece, which contains the delivery valve, which is fixed in the same way as the suction valve. On the door piece the pumps or rising main, in 9-feet lengths, are placed. It is usual to place a wind bore directly under the H-piece, leading into a cistern from which the pump takes its water, but in the example under notice a much better arrangement has been adopted. The cistern is placed just above the suction valve, so that the water may more readily follow up the plunger, and thereby cause the pump to be 'charged solid.' It is of very great importance that no vacant space whatever should be left in the pumps at the termination of the indoor stroke of the engine, for if there be a space not occupied with water, then a shock ensues, and the engine works as if working in 'fork,' or as if the pumps were taking air. A 6-inch branch and blank cover is provided in the U-piece under the H-piece, for the convenience of getting out anything which may accidentally drop into it. A blank end and 'matching' piece is put on to the H-piece under the pole case, which takes its bearing on the timber bearers below. The main rods are of Memel timber, perfectly sound and straight, without knots or faults; for the first 50 fathoms they are 18 inches square, for the next 40 fathoms 16 inches square, and for the last 30 fathoms 14 inches square. The rods are obtained as long as possible, and are jointed by means of 'strapping plates,' bolts, and nuts. The timber is sometimes cut in the form of a splice, and made to form a lap joint, but in this case the rods are all butt-jointed, the strapping plates are first firmly secured to the piece to be attached, and then the piece is put in its place on the main rods, the joint being brought up tight by powerful lifting jacks. The main rods are kept in a line by means of wood guides fixed at intervals. The plungers are cast with a plain core through them, and a little longer than is necessary for the stroke; the casting should be entirely free from specks—it is usual to cast them on the side, but we prefer to have them cast on end. The plunger is 'stocked' on the mine; a piece of Memel timber, square in section, and equal in diameter to the plunger, is obtained, about 12 feet or 14 feet longer than the 'pole.' For a portion of its length equal to that of the pole it is rounded down, and the pole is then forced on to it. When stocked it is fixed by means of staples and glands

to the main rods, a set off, or filling piece, being provided between the stock of the pole and the main rod, to bring the axis of the pole in a line with that of the pole case. Key-ways should be provided in the joint between the stock and set off, and also between the set off and main rod; when the staples and glands are firmly secured, the keys—of hard wood—should be driven. It requires great care that the 'pole connection' may be well made. Square nuts should always be used for the pit work, because it is not always convenient to have snugly-fitting spanners, and square nuts are then more easily managed than others. The stuffing box of the pole case should be packed with a well-made gasket and tallow.

"The working barrel of the 'drawing lift' is bored a little taper for 9 inches or 1 foot at the upper end, that the bucket may easily enter when dropped in from above; sometimes a door piece is provided above the working barrel, that the bucket may be examined without the necessity of drawing it; but the plan is not a good one when forking, as the water may rise too fast, and if it gets above the door before the joint can be properly made the consequence becomes serious. Directly under the working barrel is placed the 'bull's-head,' which is, in fact, a supplementary valve box, available when the 'door piece' is under water. The neck of the bull's head should be bored conical, and the valve seating geared similarly to an ordinary bucket, but the ring should be a little conical, that it may be prevented from falling through the neck of the bull's head and retained in its place. A wrought-iron loop or staple is provided on the seating, by means of which it may be fished up from above when occasion requires. A small bar is placed across the staple, which acts as a guard to the clack valve. The ring of the bucket should be of wrought iron, nearly the size of the barrel, parallel on its outer face and conical within. For the convenience of removing the doors and replacing them again a chain with swivel and screw is sometimes used, suspended from a piece of timber above. For the facility of sinking, under the suction valve is suspended a turned pipe which enters a stuffing box placed above the wind bore. The wind bore is suspended in chains provided with lifting screws, for the convenience of lowering as sinking proceeds. It will be seen that as sinking proceeds it becomes necessary to lower the drawing lift constantly, and that it may be conveniently done the pumps are suspended in 'yokes' which take their bearings on timbers fixed across the shaft. Yokes are glands made to fit the body

of the pump; they are placed directly under the ribs, and when it is required to lower the lift the yokes are loosened to let the lift drop through. Each time there is a new length or pump put in, the bucket has to be lowered, and that it may be done without the necessity of making a new drawing lift connection on the main rods, the arrangement shown in Fig. 125 is introduced; a chain and hook serves to make the connection between the main rods and the pump rod, one staple only being used to steady the top of the pump rod. This arrangement affords facilities both for drawing the bucket and putting in a new pump. The pump joints are made with flat rings of wrought iron, covered with baize and dipped in tar.

"*Balance bobs* are sometimes placed below the surface to take up some of the weight of the pump rods. The connection with the main rods is usually of wood; the vibration is given by the elasticity of the wood. In the example shown in Figs. 124, 125, the connecting rod is 15 fathoms long, and it is guided and steadied by means of a plain turned pulley, which bears against a curved filling piece bolted on to the connecting rod. Plungers are sometimes substituted for balance bobs, and are, when so employed, constantly submitted to the pressure of the column of water in the pumps; they are fixed to the main rods precisely in the same way as the ordinary plunger."[1]

With the view of securing greater regularity in the motion, and of equalizing the strain on the various parts, the compound or double-acting engine has been introduced. An example of this engine is shown in Fig. 126. The high-pressure cylinder is 36 inches in diameter, and the low-pressure cylinder 54 inches in diameter, both working an 8-feet stroke in the pumps. The piston rod of each cylinder is coupled directly to the pump rods, and from the crosshead of each piston rod run two short connecting rods, attached to two bell cranks; these cranks are connected to each other at the top by the connecting rods on each side, thus coupling the two engines and equalizing their duty. From the longitudinal centre of one of the bell cranks the motion for the tappet rod is taken, and from the back of the other one; an arm is cast on each, with connecting rods for taking the crosshead for the air pump. The cylinders, with their covers and ends, are steam-jacketed, and securely bolted down to a bed plate resting on foundations of stone. The cast-iron guides for the piston-rod crosshead are bolted to the under side of the bed plate, and the bottom end is

[1] *The Engineer.*

secured to the cast-iron beams upon which the bell-crank pillow blocks and air pump and condenser are fitted. The air pump is of the ordinary kind, fitted with india-rubber valves for bucket, head, and foot valves. The condenser is a separate vessel placed alongside

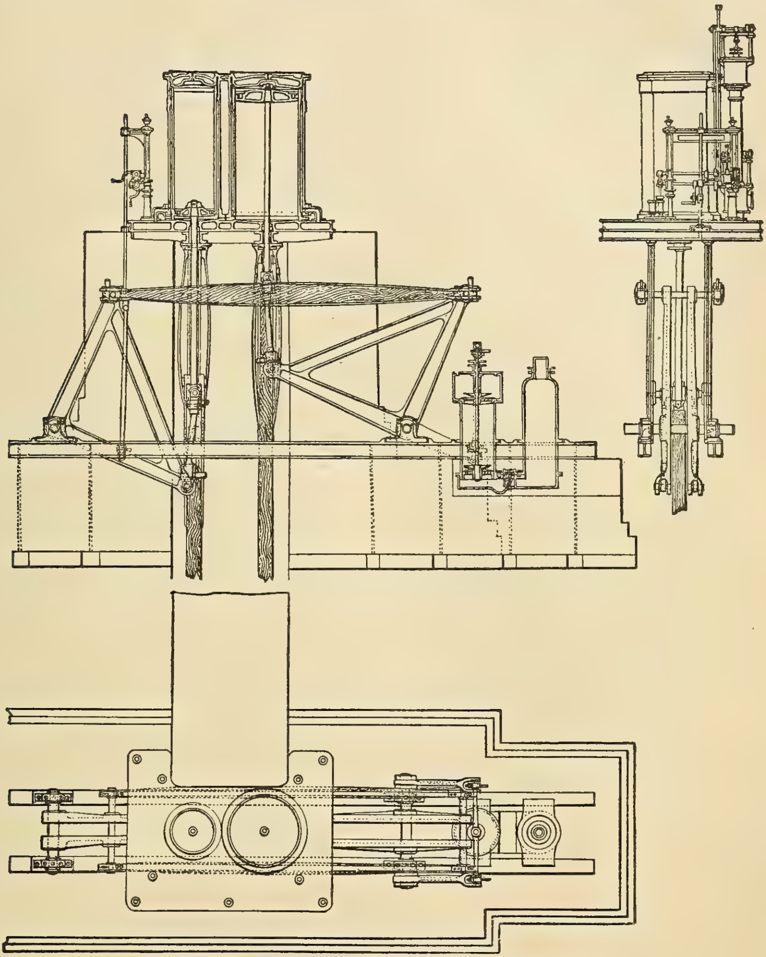


Fig. 126.—Direct-action Compound Pumping Engine.

of the air pump, the waste-steam pipe coming in at the top, and fitted with a packed gland. The valve gear for these engines is of the usual description, with cataract pumps for regulating the number of strokes. Although the machinery in these engines is rather complicated, yet when economy in fuel and great regularity in working

have to be studied, they may be beneficially used for pumping water from moderate depths and forcing or lifting it to moderate heights.

For moderate depths horizontal high-pressure pumping engines have been used, connected to two bell cranks, directly from the piston-rod crosshead, with long links, one on each side, taking the long arm of the bell crank nearest the engine; and the two bell cranks are connected to each other with wooden connecting links strapped with wrought iron, the pins for carrying these links being nearer the centre of vibration of the bell cranks; thus the stroke of the engine is somewhat longer than that of the pumps. The bell cranks are so arranged that the one goes up and the other down alternately, the steam being admitted into each end of the cylinder as in ordinary high-pressure engines. The valve mechanism is worked in a similar manner to that of the Cornish engine, with tappets, cataracts, and all the necessary starting handles. One useful feature in this class of engine is that it can be driven at a higher or lower rate of speed, or more or fewer strokes given, as the increased or diminished quantity of water in the pit may require. The exhaust steam is made to pass through a series of tubes, around which there is a constant circulation of cold water; thus the steam is partially condensed, and the water pumped into the boilers again, as in surface-condensing engines. A jet of steam, however, escapes into the atmosphere at each stroke, which is due to the tube surface not being of sufficient area, and to give the condensing vessel the requisite area would make it too bulky and expensive. By this method of allowing the exhaust steam to pass through the tubes the water around them is heated to a high degree, and it can be pumped into the boiler separately, or mixed with the water collecting in the receiver; but in either case the tube surface acts as a feed-water heater.

Horizontal high-pressure engines with slide valves and eccentric motion are sometimes used for pumping water out of coal and other mines. The valve gear is of the simplest description, consisting of a rocking lever, fitted with a link for the valve rod, and a pin for taking the gab end on the eccentric rod, which is made to throw out of gear when required. The cylinder is securely bolted to one end and the pillow block for the crank shaft to the other end of the bed plate, which consists of a heavy box casting placed on each side of the cylinder, running the entire length of the foundations, and secured at the ends with cross pieces all cast together, and

bedded on balks of timber, which in some instances form the foundation. In these engines a long stroke and low rate of piston speed are adopted, the motion for the pump being as simple as practicable to suit the requirements. The connecting rod is coupled to the pin on the crank, or cast-iron disc when so fitted, by a strap with jibs and key, and the crosshead end has a short fork forged on the connecting rod, fitted with straps, jibs, and keys. The crank shaft is generally as short as practicable, and is supported by a bearing on the bed plate, and one at the end carried on a pillow block bolted to a box girder secured to the foundations. The fly wheel is made heavy, and is placed at the middle of the shaft between the two bearings; and at the extreme end a cast-iron crank is fitted, with holes for the pin to vary the stroke of the pump when required. The motion for the pit pump is transmitted by a wooden connecting rod, strapped with wrought iron secured with bolts; the other end of the rod taking a bell crank or arm fitted to the shaft on which the bell crank is placed. The latter can be suited to any angle at which the pump may require to be placed, as in working the edge coal in certain localities.

In other arrangements, when the pumping shaft is vertical, the motion for the pump is taken from a crosshead fitted to a prolongation of the piston rod, which is continued through the end of the cylinder; the crosshead is guided the same as for the main connecting-rod end, and is connected to the bell crank by wooden rods strapped with wrought iron. In such examples the pit pumps are in duplicate, with a bell crank for each, connected together in the same way; by this means the engine is better balanced, as one set of pump rods is moving upward and the other set downward. The pillow blocks for the bell cranks are fitted to balks of timber, and the foundation for the engine is built of brickwork laid on the top of these balks, the brickwork being overlaid with timber for bedding the engine; the bed plate is secured by long bolts passing down to the bottom of the foundation. There is no feed pump connected to these engines, a steam pump being fitted for supplying the boilers with water.

There are a variety of engines for pumping water of the geared description, working plain cranks connected to bell cranks by a single rod, the bell crank having a jaw cast on it, with a pin for taking the end of the connecting rod passing through the jaws. This type of engine is generally adopted for low lifts, and is a very

convenient form for transportation, as the cylinder is of small diameter, with a high rate of piston speed, and reducing gear for the pumps. When the engines are of the horizontal type the whole of the wheel gearing should be arranged on the same bed plate as the engine, and kept as compact as possible, since detached machinery cannot be so securely bolted down on the foundations as when all the parts are well bonded together on a single bed plate.

PUMPING ENGINES FOR WATER-WORKS.

Having considered engines for pumping water out of mines, we now come to that class of Cornish engine used for pumping water for the supply of large towns. The construction of the water-works engine differs materially from that of ordinary mine-pumping engines. It is generally of the single-acting type; the whole power of the engine is employed to lift a weighted plunger placed at the end of the beam farthest from the cylinder, and which acts as an accumulator, forcing the water up the stand pipes to the height required for distribution through the mains. This height of course depends on the altitude of the city or reservoir above the source from which the pumps draw the water. The engine beam is supported on columns, carrying a spring beam on which the main pillow blocks are securely bolted, and the ends are let into and rest on the end walls of the engine house. The perpendicular motion of the piston rod at the one end of the beam and of the weighted plunger at the other end, is effected by means of parallel motion of the ordinary description, with connecting links from the crosshead, radius, and parallel bars. The air pump is worked off the centre of the back link for the parallel motion, at the main pump end; while the feed pump has a shorter stroke, being connected by means of a long rod with a pin passing through the main beam. The plug rod for working the tappets of the valve gear is attached to the beams in like manner, the valve gear being fitted with all the necessary cataracts, as in the mine-pumping engine. An engine house incloses all the machinery except the stand pipes, which are of great height, and require a separate tower. As the water in these pipes is liable to become frozen in winter, objections

have been taken to them, and as they are mainly raised to equalize the duty on the engine some authorities consider a large air vessel preferable. The pipes must be fitted with a valve loaded to a certain pressure on the delivery side, so that in the event of derangement from a pipe bursting, or from a diminution of pressure in the main, the engine would still have about the same duty to perform, as the water has to be forced through the passage covered with the loaded valve before it is taken into the air vessel, a double-beat valve being used for that purpose. This description of valve gives a large area for the exit of the water, while the surface acted upon for raising the valve is only a small portion of the total area of the passages; thus less weight or pressure on the top of the valve is required. There is also a blow-off valve fitted, and loaded to a

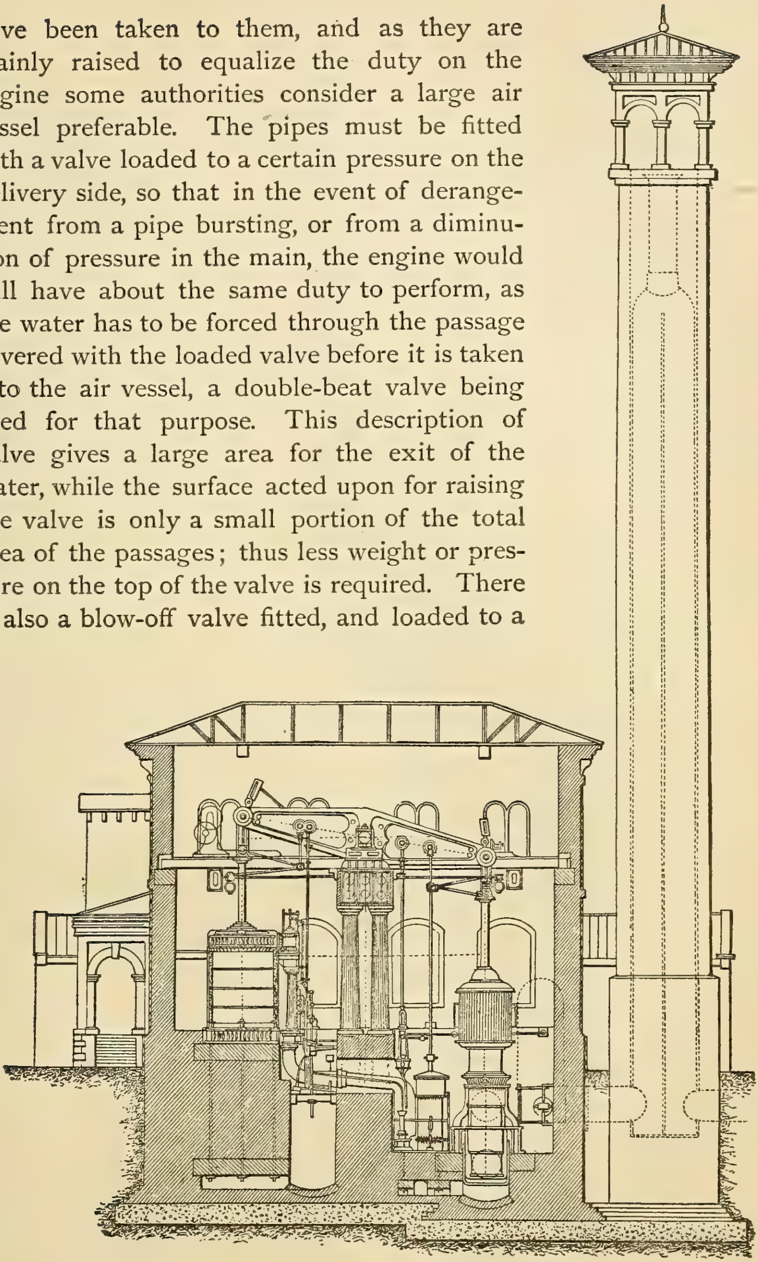


Fig. 127.—Single-acting Pumping Engine with Stand-pipe Tower.

certain weight, so that in the event of any undue pressure in the mains the water escapes, and prevents the pipes bursting. This valve acts in a similar manner to relief valves fitted to feed pumps for steam boilers, the water escaping into the well or reservoir from which it is drawn.

Double-cylinder expansion engines have been successfully adopted for water-works; where a high rate of expansion is required they work admirably, but the complication they entail is not desirable. For moderate power the single cylinder is to be preferred as sufficient for all practical purposes, but for large power we would recommend a small high-pressure cylinder working in connection with a large low-pressure cylinder, as the strain on the machinery is not so much felt, nor do the parts require to be of extra strength, as the piston rods and adjuncts would require to be, were the high-pressure steam from the boiler admitted on the top of a large piston.

We are indebted to Mr. Marten, C.E., of Wolverhampton, for the following particulars of the pumping engines in use at the waterworks there.

The two engines at Tettenhall are single direct-action non-condensing engines. The cylinders are 36 inches in diameter, and 9 feet 6 inches stroke. The plunger pumps are 13 inches in diameter, with a lift of about 300 feet. The steam is admitted to the cylinder at a pressure of about 35 lbs., and is cut off at two-thirds of the stroke. The boilers are cylindrical, two in number, 26 feet in length and 6 feet in diameter, with two tubes in each 25½ inches in diameter, and internal flues; the flame from each fireplace passes along the tube, thence round to the front, again by the side of the boiler next to its tube, where the two unite and pass along the bottom into the chimney. The boilers are covered with loam or moulding sand to a depth of about 6 inches from the top. This substance, which should be protected by a roof from blowing away, is found to be a very good non-conductor, little heat radiating through it to the upper surface; it has also this advantage over nearly all other materials employed for the same purpose, that no condensation can take place in it within 2 or 3 inches of the boiler plates, since for that distance it forms a sand bath as hot as the steam, which, in the event of a leakage, blows through it dry, and consequently corrosive action on the plates is prevented. When escape and condensation of steam takes place, it is detected by a moist patch on the surface of the sand. With a material of this

description, any portion of the top of the boiler can be uncovered with a shovel, and examined at once. For the purpose of experiment, steam blows at two places in the boilers at Tettenhall were suffered to remain unrepaired for a couple of years, in order to test the value of this covering, and the result was an entire absence of corrosive action on the plates. In the opinion of Mr. Marten loam sand is much preferable for this purpose to any other material, provided that it is protected by a roof or covering. It is much cheaper than felt, brick, or sheet iron casing with air space; and much superior to furnace ashes, cinders, or riddlings, which are often placed over boilers, as these substances frequently contain acids and other chemical impurities, which on being brought in contact with waste steam act very injuriously on wrought iron.

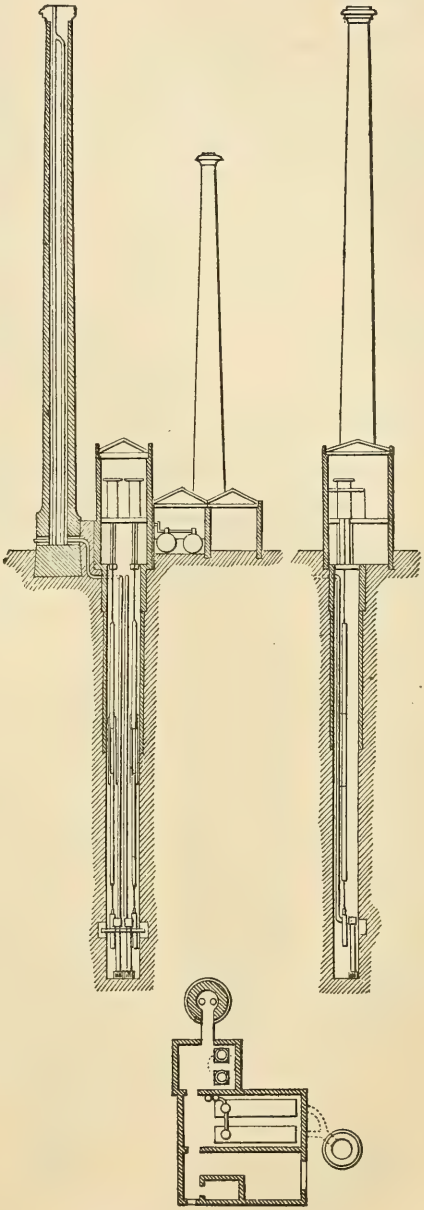


Fig. 128.—Tettenhall Pumping Engines. Elevations and Plan.

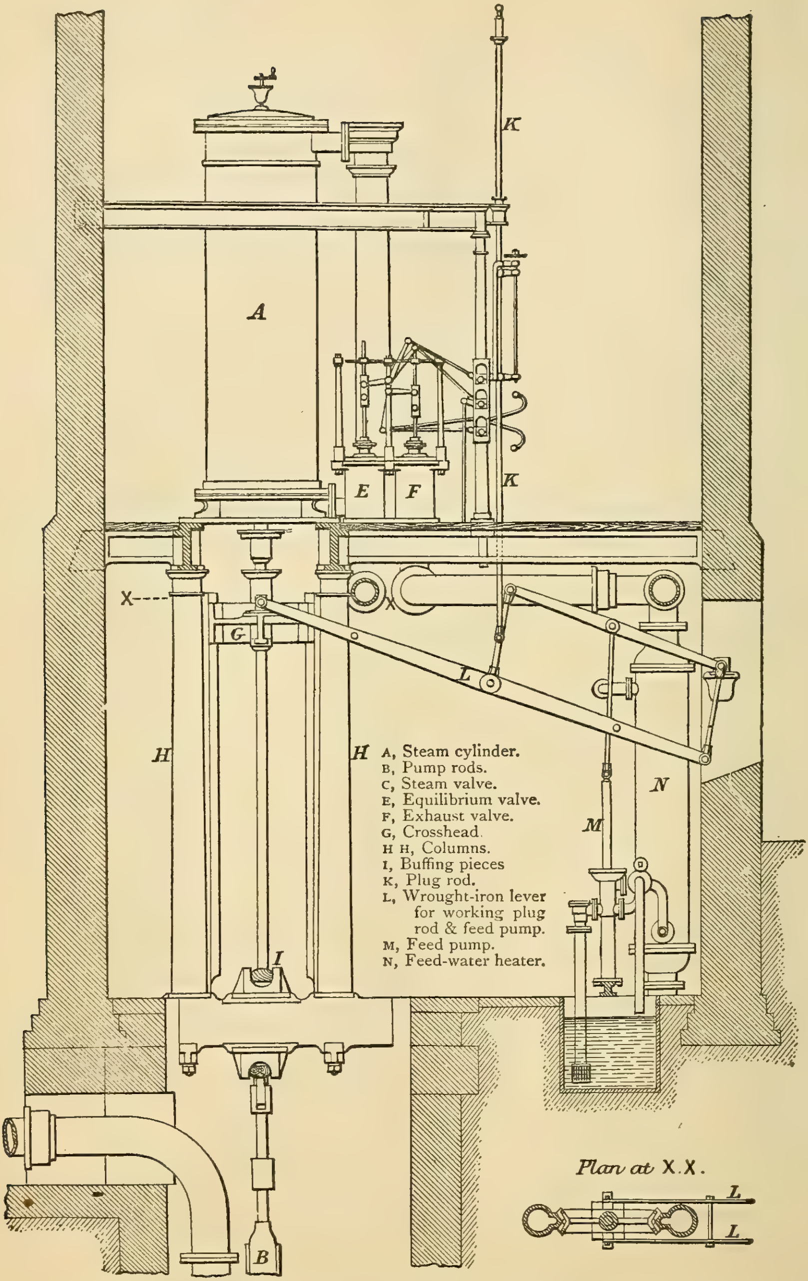


Fig. 129.—Tettenhall Pumping Engines. Side Elevation.

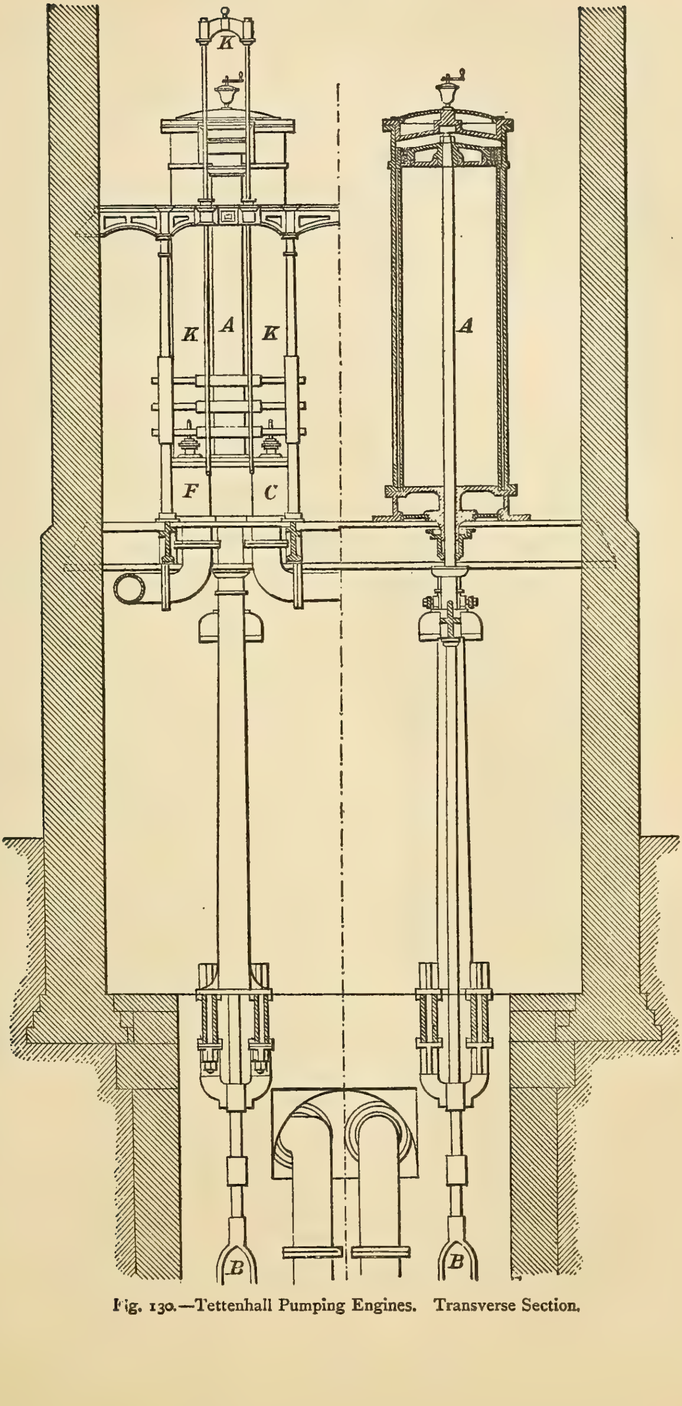


Fig. 130.—Tettenhall Pumping Engines. Transverse Section.

The steam, equilibrium, and exhaust valves are of gun metal, and on the double-beat construction. Their areas are as follows:—

Steam valve,............................	50 sq. in.	= $\frac{1}{20}$th area of cylinder.
Equilibrium valve, ...	50 ,,	= $\frac{1}{20}$th ,,
Exhaust valve,..........................	78 ,,	= $\frac{1}{13}$th ,,

The piston rod and pump rod are connected with a crosshead working on V-slides attached to the supporting columns. The plug rod and the valve motion are worked from a slight wrought-iron beam under the cylinder floor, connected at one end to the crosshead, and at the other slung to parallel links. The feed pump is also attached to this beam, the water for the feed being passed through a heater situated in the corner of the engine house, and formed by an enlargement of the waste-steam pipe. This heater is 1 foot 6 inches in diameter; the feed pipe is conducted along its centre for some distance, and occupies about two-thirds of its area. The engine is regulated by a water cataract, governed by a small ratchet wheel and screw. The number of strokes per minute varies from three or four to ten or eleven, the average speed of piston being 130 to 140 feet per minute; the quantity of water delivered per stroke is 56 gallons. The pumps are of the plunger type, and have the valves placed at the top of the barrel; by this means no air can collect at the top of the pump, as in ordinary plunger pumps for colliery purposes. The area of each plunger is 132 square inches, and the pressure on its bottom is 130 lbs. per square inch—making a total dead load of 17,160 lbs., equal to a pressure of 16¾ lbs. per square

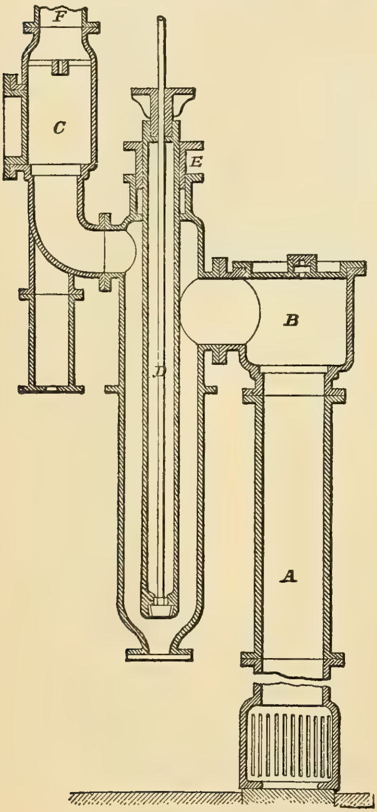


Fig. 131.—Sectional Elevation of Pump.

A, Suction pipe. B, Suction-valve chest. C, Delivery-valve chest. D, Plunger. E, Stuffing box and gland. F, Stand pipe.

inch on the surface of the steam piston. These engines are worked at a fair duty, performing about 27,000,000 lbs. lifted 1 foot high per minute, with a consumption of 1 cwt. of the small slack in the neighbourhood; with Newcastle or Welsh small coal they would perform a duty of 36,000,000 lbs. The pump valves are of the ring description, rising on a central spindle; they are made of cast iron galvanized, beating on wooden faces. Originally they beat upon a mixture of lead and tin, but this soon became loose in the seating, causing leakage; oak was then tried, but the acid peculiar to this wood corroded the cast iron, and it had to be discontinued; lancewood, box, and beech have also been tried, but no wood answers so well as holly, which is now used for this class of valve. The area of the suction valve is 325 square inches, being about two and a half times the area of the plunger; and that of the delivery valve is 163 square inches, or about one and a third times the area of the plunger. The enlargement of the suction valve to this extent is found to be very serviceable where the velocity of the plunger is likely to be great in the ascending stroke. The water was originally delivered over a stand pipe 180 feet high, whence it flowed by gravitation to the town; but now a reservoir is substituted, and the stand pipe dispensed with.

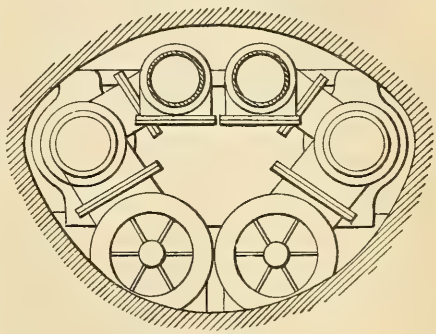


Fig. 132.—Plan of Pumps.

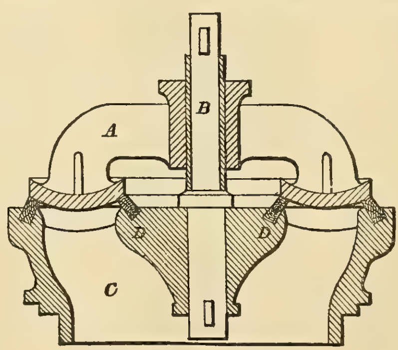


Fig. 133.—Valve for Pump.

A, Valve. B, Guide bar. C, Valve seat. D D, Wooden beats.

The engine at Goldthorn Hill is a low-pressure condensing beam engine. The cylinder is 48 inches in diameter, with an 8-feet stroke. The boilers are 30 feet long and 7 feet in diameter, with two tubes, 2 feet in diameter beyond the furnace, and 2 feet by 2 feet 4 inches

at the fireplace. The pressure of the steam is about 15 lbs. per square inch.

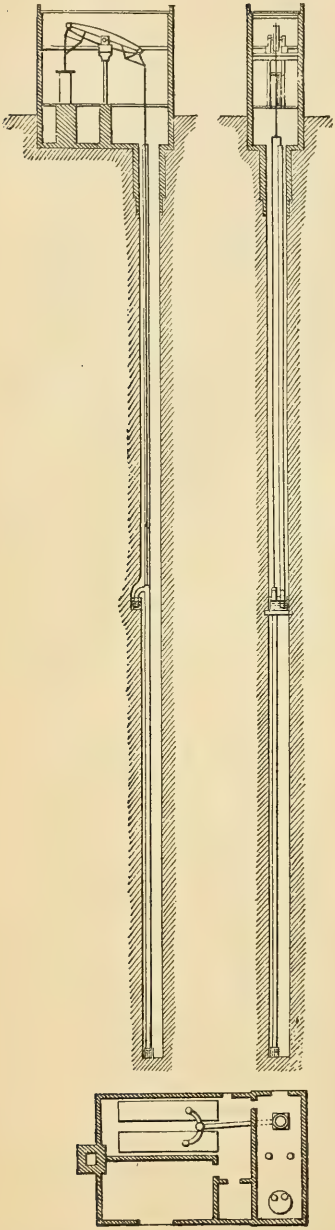


Fig. 134.—Engine at Goldthorn Hill Waterworks. Elevations and Plan.

To avoid the almost constant trouble caused by leakage at the steam valves on the boiler tops, from expansion and contraction of the main range of steam pipes, the main steam pipe should have a quadrant curve between the boilers, so as to allow for expansion and contraction without a thrust sufficient to break any joints. This arrangement is useful and efficient when there is one steam pipe leading off from between two boilers; when, however, the steam pipe leads off from one side, or where there is a range of more than two boilers, it is not applicable, and in such cases, in the absence of packed expansion joints, no plan is so simple and effective as the wrought-iron diaphragm joint, consisting of a couple of circular wrought-iron plates, about two and a half times the diameter of the pipe, dished out about 3 inches, and rivetted together at the outer rim and to flanges on the main range of the steam pipe.

Another useful, although frequently overlooked, point of detail in connection with the boilers, consists in leading the hot and cold feed and blow-off into and out of the boiler through the same pipe. This arrangement avoids the numerous holes usually cut in boilers for these purposes, and any impurity which may enter the boiler with the hot and cold feed is deposited near to the blow-off. In the present instance the pipe is of wrought

iron, and is rivetted on the under side of the front end of the boiler. The arrangement of the valves is somewhat similar to those of a bath, where the hot, cold, and outlet valves all take off the same pipe. It is also important that the feed should enter the coldest portion of a boiler, which, from the action of the currents in those with internal flues, is just under the fire grate. When this is not attended to the seams and rivets are apt to leak from the sudden changes of temperature to which they are subjected.

Instead of delivering the water over a stand pipe, as originally in the Tettenhall engine, the Goldthorn Hill engine delivers through an air vessel into two reservoirs lying near the engine, holding together 1,500,000 gallons, and raised about 20 feet above the top lift. The reservoirs are arched over, and covered with 2 feet of soil, for the purpose of preventing vegetation in the water and variation in its temperature. These objects are well secured, as the water remains for months at the same temperature, and perfectly free from all vegetable or animal impurities. The reservoirs are kept from being overfilled by a self-acting check valve, which shuts against any supply beyond a certain limit; and the man in charge of any pumping engine at a distance at once knows when to stop work. The valve is so arranged that when the engine ceases to work the supply from the reservoir to the town is maintained through the flap valves placed underneath the self-acting stop valve. The object of a stand pipe is that the water may be always delivered from the engine over one uniform height, and consequently of one uniform pressure on the engine, whatever varying circumstances may affect the delivery after the water has once passed the top of the stand pipe. For this purpose it is useful, but it is rather a costly and unsightly mode of attaining what in practice is found to be an unnecessary degree of perfection, as at a tithe of its cost all the necessary safety can be secured by pumping into an air vessel with a self-acting valve on the delivery side, so that, in case of a pipe bursting, or any sudden diminution of pressure taking place, it would be impossible for the engine to "go out of doors," as it is technically termed, at more than a certain regulated speed, by the partial contraction of the area of discharge through means of the check valve. Unless, too, the stand pipes are carefully cased in winter they are in great danger of being frozen, and very serious consequences have arisen from this cause. The great weight of the column of water requiring to be set in motion from a dead stand at

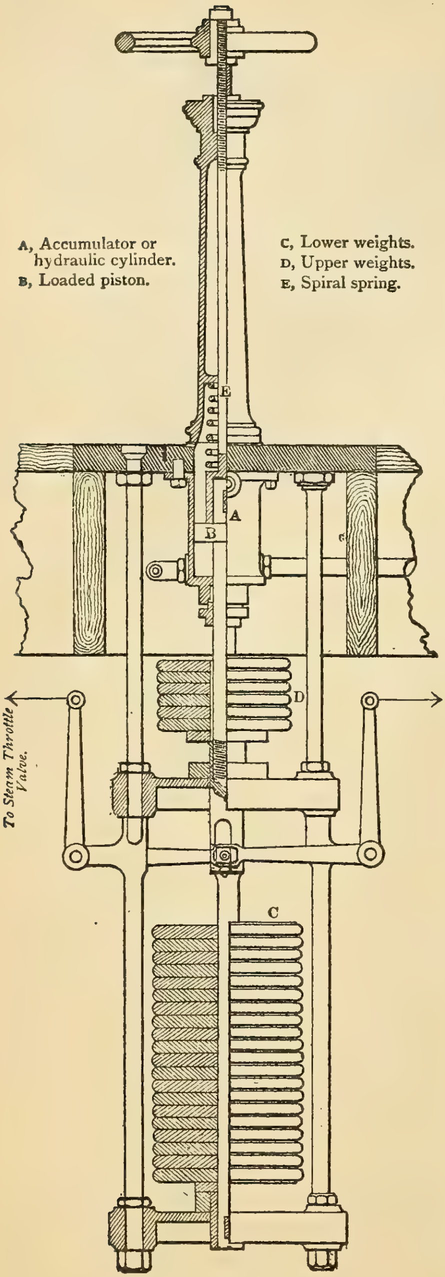


Fig. 135.—Valve Regulator.

each stroke of the engine is also an objection to the use of the stand pipe.

As a substitute for these tall stand pipes, the following arrangement has been adopted in the St. Petersburg water-works, recently carried out by Messrs. R. Laidlaw & Son of Glasgow. A throttle valve or regulator is placed so as to be controlled by the pressure of the water in the main. The pressure acts through a small accumulator or hydraulic cylinder fitted with a loaded piston and attached to the regulator. This loaded piston, as it moves with the varying pressure in the mains, acts on the throttle valve, and thus regulates the motion of the engines. A further arrangement was made whereby the steam would be automatically and instantaneously shut off if any burst took place. Fig. 135 shows the arrangement adopted. The lower weights are slightly less than the pressure on the water piston, and thus the piston spindle is kept in contact with the upper weights; the steam valve being then half open, any increase of pressure thus causes the upper weights to be raised and the spiral

spring is compressed and the regulating valve closed. If a burst takes place the lower weights drop and instantly close the steam valve.

The successful working of any pumping engine is dependent in a great degree upon the perfection of the pump valves, which must be so arranged as to deliver the water with ease and rapidity, and without any concussion in closing. As an illustration of the great practical importance of this question, it may be mentioned that when the Cornish pumping engine was first used for water-works purposes on a large scale, it was on the point of being altogether abandoned on account of the imperfection of the pump valves. The valves were of large area, and constructed on the old butterfly principle, so that, under the heavy pressure at which they were worked, the concussion caused in shutting was so violent as to occasion serious alarm for the safety of the machinery and foundations. The difficulty of constructing a valve which should present a maximum area of discharge with a minimum area of surface exposed to the concussion of the recoiling load at the termination of each stroke of the pump appeared for a time insurmountable, but was, however, happily got over by the introduction of the double-beat valve.

This valve, as already explained, has the upper area contracted, and by the difference of the upper beat and the inside of the lower one a surface is afforded for the water to act upon in lifting and shutting the valve. The valve having two points for the water to escape by, a very slight distance of lift gives a large area for discharge; and the area upon which the recoiling column descends being only the difference between the upper and lower areas, and not the entire area of discharge as in the old butterfly valve, forms a surface insufficient to cause any concussion. This valve also affords, under all circumstances, a means of regulating the pressure tending to shut the valve, whatever may be the height of the column of water or the total pressure of the recoiling column, by adjusting the difference of area of the upper and lower beats inversely in proportion to the height of the column.

For the ordinary purposes of small lift pumps and colliery engines the butterfly valve is serviceable, as there are no expensive faces to be ground up or deranged by impurities or grit in the water, and it can be readily repaired on the spot. For a higher class of work there is no description of valve answers better than the double-beat

ring valve, similar to the one employed in the engines at Tettenhall and Goldthorn Hill. Large valves of this construction, from 16 to 20 inches in diameter, answer well made of cast iron with wooden beats; smaller valves, from 8 to 15 inches in diameter, are better made of gun metal, working face to face, some of the latter description having worked for more than two years, under a pressure of 260 feet of head, without any perceptible wear.

At the Hull water-works a special description of valve has been adopted in one of the pumps with great success. It consists of a

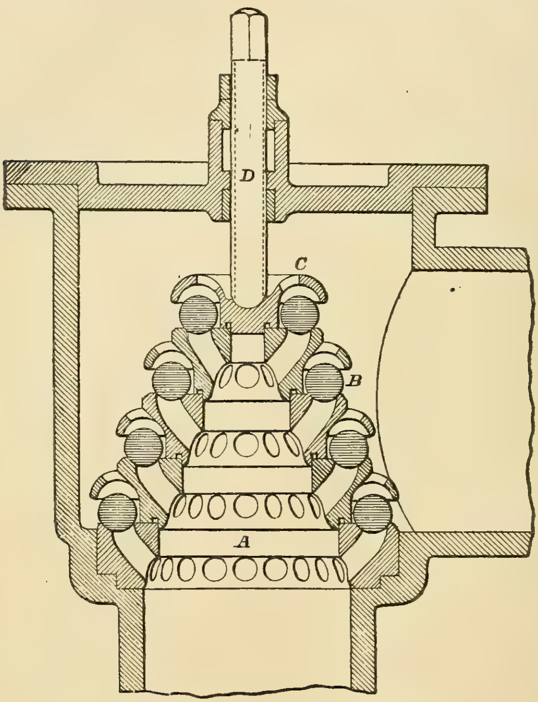


Fig. 136.—Gutta-percha Ball Valves on Metal Seatings.

A, Valve seats. B, Gutta-percha balls. C, Guard pieces. D, Holding-down bolt with stuffing box and gland.

pyramid of circular seats, one above another, in each of which there are a number of small circular beats about 2 inches in diameter, into which a corresponding number of gutta-percha balls drop. It is 22 inches in diameter, and works under a head of 160 feet, in connection with a plunger pump with a direct-action steam cylinder. The action of this valve, as will be seen from Fig. 136, is very

simple. It was substituted for the double-beat valve in use, and immediately upon starting it lightened the burden of the engines about 168 lbs., and has since given great satisfaction. This valve possesses other advantages. In the first place it is much safer than any other form of valve, as will be easily seen. Supposing a piece of wood or other material should pass through the pump, as is frequently the case: if the wood should be caught on the beat of the ordinary valve, it would hold the whole valve open and let the engine "come out" with a run, possibly causing considerable damage; but with the small balls of this valve a piece of wood so caught could only affect one out of fifty-six balls—so small a percentage of the whole opening that it would merely enable the man in charge to perceive that there was some trifle amiss by an increase of leakage. In the second place, the balls, being nearly of the same specific gravity as the water, are floated open the moment the current turns in their favour; whereas in all other valves, in addition to the column of water to be lifted, there is also the weight of the heavy metal valve to be opened and held suspended during each stroke. With large valves this point becomes one of great importance, as they often weigh 5 to 6 cwts. each. Again, in this valve, whilst the area of discharge may be made fully equal to that of the plunger, the area exposed to concussive action in closing is reduced to the smallest possible limits, being practically the impinging force upon one ball, the last one that shuts, or $\frac{1}{56}$th part of the total area of beating surface; this is owing to the fact that the balls do not all rise to the same height above their seats, and consequently, as the force of the current acts upon each ball separately, on the cessation of motion each shuts in accordance with the height it has to fall, and a communication exists between the water on the upper and under side of the valve until the absolute closing of the last ball. The result is, that although the difference in time between the falling of the various balls must be exceedingly minute, it is such as practically to prevent all concussion. Lastly, the valves constructed on this plan are very easily repaired. It is only necessary to keep a few spare balls ready, to be inserted in the place of any that may become damaged; and the old ones, melted and recast in a mould kept for that purpose, are again as good as new.

Where it is proposed to work with a high pressure of steam, cut off so as to allow of a considerable expansion, the beam engine is to be preferred to the direct-action engine; the latter, as a rule,

when working under a high initial pressure, is apt to start off at a speed which jars and strains the whole of the machinery. Besides, the speed attained by the piston as driven indoors at the beginning of the stroke is many times greater than the average velocity per minute, and therefore, unless all the parts are made proportionally, the bearings very quickly wear out, and the machinery is loose at every joint. In a beam engine, on the other hand, a very large proportion of the initial force is absorbed in overcoming the inertia of the heavy beam, which thus serves as a reservoir of surplus force in the earlier part of the stroke, giving it out during the later part, with the result that a comparatively steady velocity is maintained throughout the stroke, much to the advantage of the whole machinery; indeed, it is only with this adjunct that expansion can be safely carried to a very high degree. The beam, in fact, acts like a fly wheel, storing force as required, and is attended with precisely the same beneficial results.

For pumping a large quantity of water through an unusually great length of main pipe, under a heavy pressure, a description of engine may be preferred, consisting of a pair of high-pressure expansive double-acting beam engines, coupled together at right angles to the fly-wheel shaft. The pumps in this engine should be of the combined bucket and plunger type. Each pump should have an air vessel and back-flap valve, with a blow-off valve loaded to a certain weight, so that in the event of any recoil in so great a length of main the pumps would not burst. Along the main pipe, at each 50 feet of elevation above the pumps, a back-flap valve is required, so that in case of any pipe bursting the whole main would not be run dry. The leading point to be kept in view in the design and construction of engines for such purposes is the maintenance of a constantly uniform flow of water through the main pipe from the pumps. This is provided for by the compound double-acting pumps and large air-vessel accommodation, together with the coupling of the engines at right angles. Many engineers prefer a double-cylinder engine for conducting expansive operations; but although in some cases such an engine is advantageous, as for driving machinery where great regularity of motion is a desideratum, yet for large pumping engines the single cylinder is preferable, as double-cylinder engines are much more complicated, and all useful degrees of expansion can be obtained sufficiently with a single cylinder.

The next example gives the plan of the water-works as adopted at Berwick-on-Tweed. The works comprise two tanks for storing spring water, one with the top water at a level of 16 feet above ordinance and the other 12 feet higher. The upper tank, which occupies the site of an old quarry, is 80 × 50 feet and 7 feet deep, and has three walls built of dry rubble stones, to admit the water from the springs

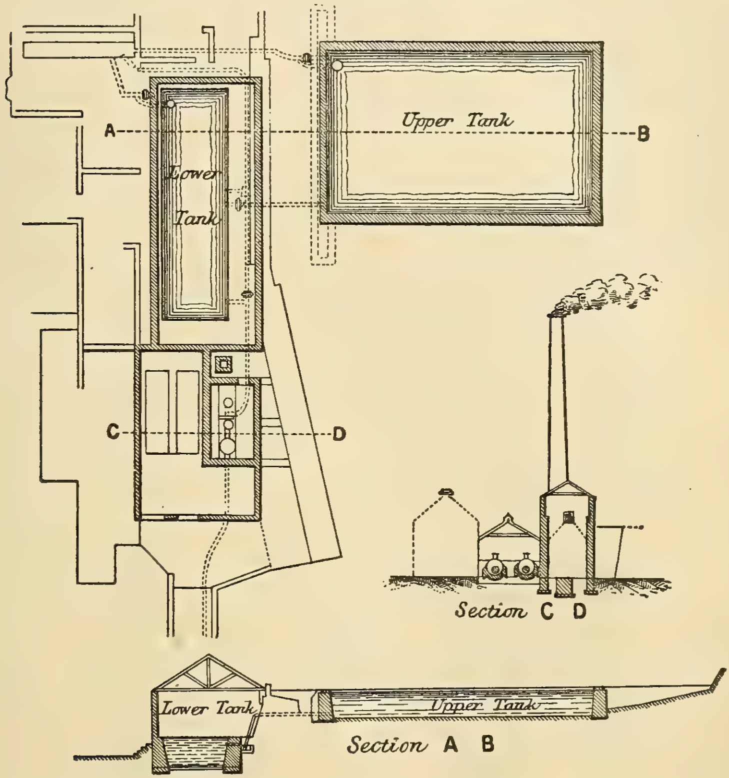


Fig. 137.—General Arrangement of Tanks, Engine and Boiler Houses, Berwick-on-Tweed Water-works.

rising behind the walls; the wall next the river is built of water-tight masonry in cement, with a puddle wall at the back of it. The lower tank, which is 70 × 20 feet and 7 feet deep, has solid walls like the large one, and receives the water from several springs, which rise at a lower level than those stored in the upper tank. An engine and pump and boiler, with engine and boiler house, complete the works at the collecting ground; and a 9-inch rising main conducts

the water to a high-level reservoir, placed at a level of about 200 feet above ordinance. The springs, of which there are several, are estimated to yield 230,000 gallons in the twenty-four hours, and the engine working ten hours per day is calculated to raise 61 cubic feet per minute. The height being 178 feet, and the length of track 8145 feet, with a diameter for the rising main of 9 inches, the head allowed for friction was 24 feet, found by the formula $h = \frac{Q^2 l}{22 d^5}$, which makes a total height of 202 feet. To calculate the horse-power required to raise the water to the high reservoir: By the ordinary method $\frac{61\frac{1}{2} \times 202 \times 62\frac{1}{2}}{33000}$ we have a result of 24, and adding a fourth more for loss = 30 horse-power for the engine. It is worthy of remark that the pressure gauge on the air vessel registers an increase of 10 lbs., which is equivalent to 24 feet of head while

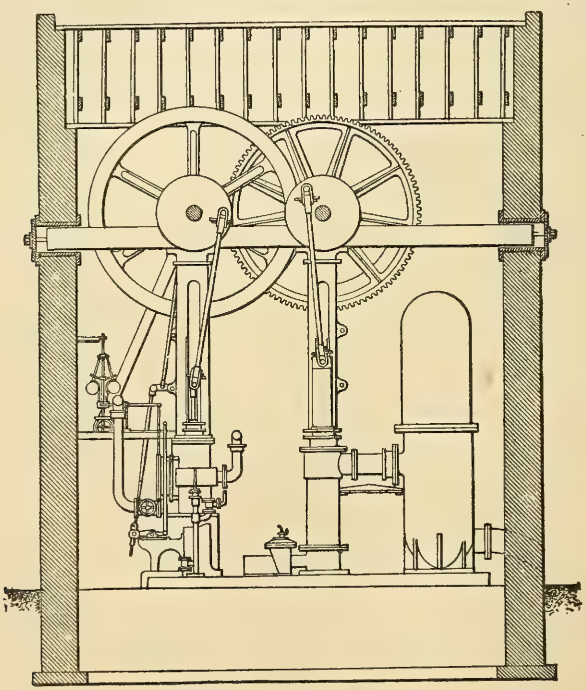


Fig. 138.—Engine and Pump.

working, and when standing the pressure is reduced to that due to the statical pressure, namely, 178 feet.

The engine, which is non-condensing, and is placed vertically, is

calculated to work with a pressure in the boiler of 40 lbs. per square inch. The piston is 17 inches in diameter, the stroke being 3 feet, and the number of revolutions of the crank about thirty-five. The pump is double-acting, consisting of bucket and plunger; the diameter of the barrel is $18\frac{9}{16}$ inches, that of the plunger $13\frac{1}{8}$ inches, with a stroke of 3 feet. The bucket packing consists of rings of gutta percha about 1 inch square in section, let into grooves cut in the bucket; two holes, ½ inch in diameter, are bored in the top, communicating with the grooves, the water pressure being always constant presses out the rings of gutta percha, making them perfectly water-tight. The valves are of the ordinary flap kind; a large air vessel is fitted to the pump, 3 feet 6 inches in diameter and 14 feet 6 inches high. The motion for driving the pump consists of a pinion on the engine shaft and spur wheel on the pump shaft, the gearing being in the proportion of 3 to 1. The fly wheel on the engine shaft is 11 feet in diameter, and weighs 5 tons 12 cwts.; a balance is placed on the spur wheel to counterpoise the weight of the pump ram. The boilers are 26 feet long and 6 feet 6 inches in diameter, with a single flue 3 feet 3 inches in diameter; the fire grate is arranged underneath, with return side flues; thickness of plates in body of boiler, ⅜ inch; of end plates, ½ inch. The chimney stalk is 84 feet high, 7 feet 6 inches square at the level of the ground, and 3 feet 6 inches square at the coping. The boiler is fed with a small plunger pump, worked off the end of the piston crosshead, the water being previously heated in a tank by the exhaust steam. The engine and pump cost £950. The rising main, 9 inches in diameter, has turned and bored joints except where lead and yarn ones were required for sharp bends; and also four air and four scouring plug valves with a clack valve immediately above the air vessel and another half-way up the track. A branch pipe leads into the lower service cistern, fitted with a self-acting ball valve, 6 inches in diameter. The pipes cost when laid about 12*s.* per lineal yard. The actual work done by the engine can be determined by means of a cast-iron measuring box placed at the

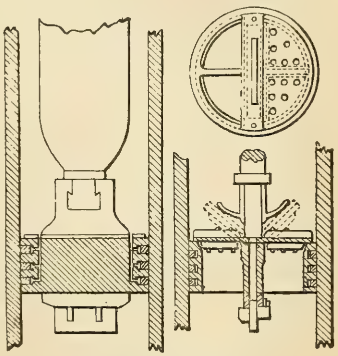


Fig. 139.—Pump Bucket.

upper end of the pipe, with a trough having a flap valve in the bottom for passing the water direct into the cistern if required.

By means of an indicator diagram we can calculate the amount of work required to raise the water from the lower tank to the high reservoir as follows:—The measuring box is 6 feet × 3 feet 3 inches × 3 feet 1⅜ inch, and has a capacity of 60·64 cubic feet. The averages of four experiments made by the engineer for the works gave 58·25 seconds as the time required to fill the box, which represents a discharge of 62·5 cubic feet per minute. The area of the plunger of the pump being ·9398 foot, and the double stroke 6 feet—the engine making thirty-five revolutions per minute, which represents 11·66 of the plunger—gives a theoretical discharge of 65·73 cubic feet per minute, and shows a ratio between the theoretical and actual of 100 : 95, or a loss of 5 per cent. This represents an amount of work = 62·5 cubic feet, weighing 3906 lbs., raised 202 feet high, which is equal to an expenditure of 23.9 horse-power. The indicator diagram showed an effective pressure of 23 lbs. per square inch, which with thirty-five strokes per minute at 6 feet, with a piston of 224·5 square inches, is = 33 horse-power, showing a loss for friction, &c., of 27 per cent.

CONSUMPTION AND COST WITH VARIOUS KINDS OF COAL.

	per ton.	per hour.	per horse-power per hour.	per horse-power per hour.
Broomhill Nuts	at 6/6 ...	burn 3·7 cwts. ...	= 17·3 lbs. ...	= ·602*d.*
Berwick Hill	,, 9/6 ...	,, 2·5 ,, ...	= 11·7 ,, ...	= ·586*d.*
Scremerston	,, 9/6 ...	,, 2·7 ,, ...	= 12·6 ,, ...	= ·631*d.*

The above table compares the consumption and cost of coal with the actual quantity of water delivered, which is equal to an expenditure of 24 horse-power. If we compare the expense of working this engine with larger ones in use at some of the English water works, and use the same standard—namely, the cost of raising 1000 gallons 100 feet, which is equal to 1,000,000 foot-pounds, we find—

The Trent Water-works Company at Nottingham	cost ·287*d.*
Boulton & Watts, 29 horse-power, 1809, condensing,	,, ·543*d.*
,, ,, 30½ ,, ,, ,,	,, ·358*d.*
,, ,, 76 ,, 1828, ,,	,, ·333*d.*
Berwick Pumping Engine, 1871 (high-pressure),	,, ·340*d.*

STAND PIPES, ETC.

Stand pipes were originally introduced to equalize the weight on the engines, and give the required pressure in the main pipes for the town supply. The arrangement under notice was erected at Tettenhall, and consisted of two pipes, one of them open at the top, inclosed in a tower of brickwork, as shown in Fig. 140.

We are indebted to Mr. Marten, C.E., for the following description of its action:—The engine having only steam on the under side of the piston lifted the pump rods, and their own weight was just sufficient to bring them down along with the plunger of the pump if the stand pipe was only full to the junction at the top, but it was not enough to let them force the water to the top of the tower. When the town required all the water the engine pumped regularly, being worked by a cataract to give the requisite number of strokes per minute; but if the town did not take the water the engine stood, because the rods were not heavy enough to make the down stroke. Whenever the town drew off some water the engines started again. The state of the water in the stand pipe was shown in the engine house by a mercury gauge, and the engines were regulated to keep the stand pipe full up to the junction. There were no escape valves, because they were not needed; if by any chance the sudden shutting of the large mains in the town, or air returning up the main, threw the water over the top of the stand pipe, it filled the cap of the tower and ran out at small holes, falling like rain, but this very seldom happened. When there is much danger of overflow near a town an overflow pipe is fitted, which allows the water to flow into the reservoirs from which it is pumped. At Tettenhall there was no provision made for breaking the fall of the water in the descending leg of the stand pipe. This want caused much air to be carried into the mains, so that the water when first drawn was often as white as milk with the minute bubbles of air, but it cleared in a very short time. The chief use of the stand pipe was to render undue pressure on the mains impossible, as there was at first no reservoir. When a reservoir exists, however, always open to the pumping main, it serves the purpose of a stand pipe, and prevents any undue pressure.

In some cases, as the South Staffordshire water-works at Bromhills (Fig. 141), the stand pipe is placed on a hill on the line of the main, about half-way between the engine at Lichfield and the main reser-

voir at Walsall, and it there acts both as an air pipe and a safety

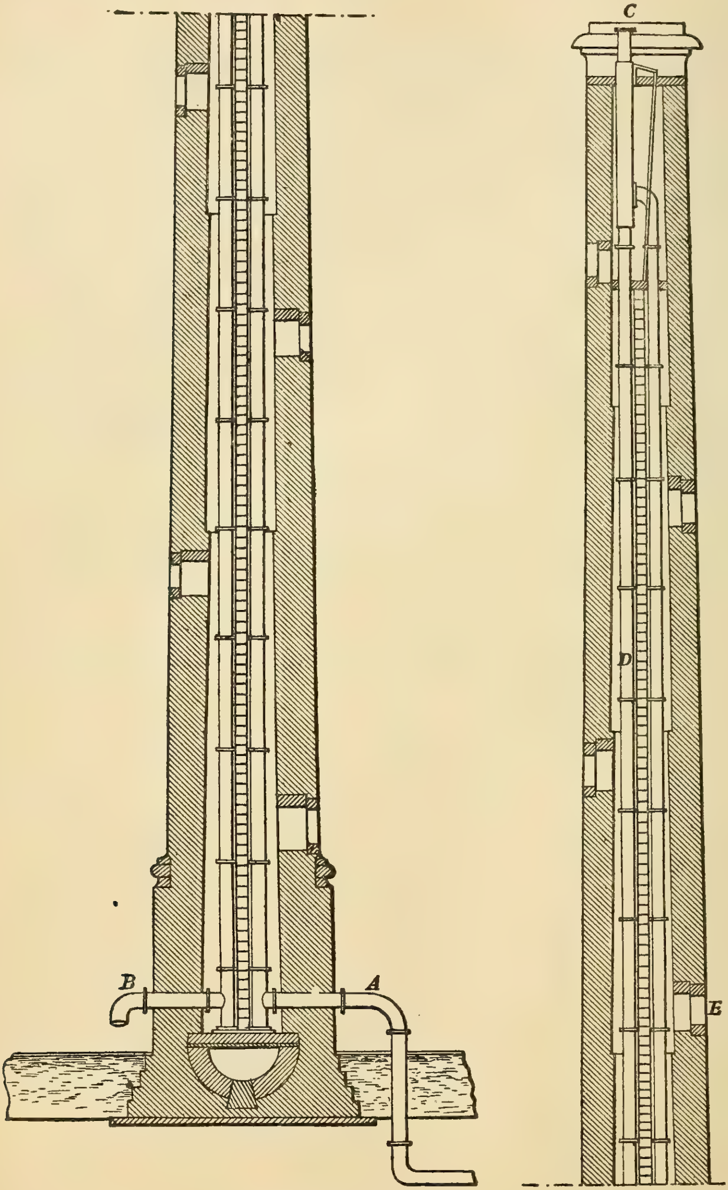


Fig. 140.—Stand Pipe and Tower.

A, Pipe from the pumps. B, Pipe to the town. C, Cap. D, Ladder. E, Windows.

pipe. At Bromhills there is only one stand pipe, open at the top, and placed in the centre of a brick tower; if it overflows the water falls down the tower, and flows into a canal.

Mr. Marten states that he has found a 6-inch weighted valve, on a 9-inch pumping main, do as well as a stand pipe, and it prevents the required pressure from being exceeded. At Stourbridge a small district near the reservoir needs higher pressure than the reservoir gives, and a valve on the main is weighted to give the required

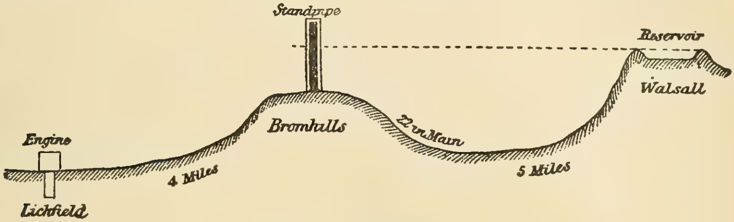


Fig. 141.—Stand Pipe, &c.

pressure, the escape water passing into the reservoir. This valve can be even made self-acting, as it does not quite close, and allows the quantity of water to pass delivered by the engine at its ordinary speed; and when the engine delivers the quantity of two or three extra strokes, the pressure rises, but never beyond the 50-feet extra head required. As the main to the reservoir is also the supply main there is a back-flap valve on it in the same box as the weighted valves, which opens whenever the engine stops, and lets the reservoir water return. There is also a similar valve at the engine house, about half a mile from the reservoir, which enables the engine to send direct into the town without a reservoir or open-ended pipe; but this plan is not adopted except in cases of repair of the main or reservoir.

Various valves are in use for preventing the engine running away if a main pipe bursts, and they are generally placed beyond the air vessel when so fitted. A catch, kept open by the pressure, is sometimes used; if the pressure in the main pipe falls, the engines are stopped by this catch preventing the steam valve from opening. Mr. Marten states that when testing a long main he was surprised to note the instantaneous action of the water; any alteration of the pressure was so instantly seen at the other end that no difference in time could be detected. On the South Staffordshire main from Lichfield to Walsall, at every 20 feet or so of rise a *back* stop valve

is fitted to prevent the return of the water if the engine is stopped or a pipe bursts. In the case of the latter accident it is of importance to prevent much water escaping, as the pipe is laid for some distance along a railway embankment formed of gravel and sand, easily washed away. During the testing of the main one pipe burst where there had been a chill in the casting, but so little water came out as to do but little damage to the embankment. The engine stopped because of the sudden drop of the pressure acting on the catch already referred to; and the return of the water was prevented by the back valves, even the water between the burst and the next valve placed above being retained, as no air could get in except in gulps at the break.

Many things which were once considered necessary to the safety of water-works are now superseded. The constant system, or one reservoir for the whole town, instead of each customer having one for himself, has caused great change. Instead of the supply pipes being led off small pipes called "riders," they are put direct into the main, and all the ends of the main are connected, so as to give greater circulation to the water. The use of cisterns is discouraged as much as possible, as they are likely to deteriorate the quality of the water. Separate pipes to the reservoir—one to pump through and the other to supply through—are not used, but only one pipe for both purposes.

It often happens that the supply is obtained from a spot between the town and the high ground where the reservoir can be made: one pipe from the reservoir is then found sufficient, and the engine pumps into it. If the town, as in the middle of the day, requires all the water, it is sent direct into it; when the demand falls off, it is partly delivered into the reservoir; if there is an extraordinary demand, both the reservoir and engines supply the town. By this arrangement one main answers, and it may be much smaller than if two were used, one to the reservoir and another from it to the town. Much of the water, also, is pumped at a less pressure than would be needed to pump it entirely into the reservoir.

Stand pipes may be considered as among the precautionary contrivances once deemed requisite for supplying water to a town; but the supply can be obtained direct from an engine as easily and safely by properly loaded valves, although it is found a more expensive plan. The engines do wretched duty, as the calls upon them are so irregular. An engine always does best when working regu-

larly at full speed, and therefore a reservoir to receive the pumped water should be provided if possible.

When pumping under a heavy pressure it is usual to have an air vessel to each engine on the delivery pipe beyond the pumps; and sometimes a larger one is placed on the main pipe into which the others deliver. Of course care must be taken that each air vessel has its full complement of air; sufficient is usually drawn in

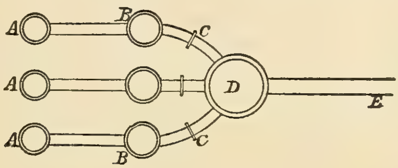


Fig. 142.—Air Vessels.

A A, Pumps. B B, Air vessels. C C, Sluice valves. D, Main air vessel. E, Main pipe to the town.

by the pump, and a very small hole or tap is sometimes inserted to supply it.

When more than one pump is arranged for pumping into an air vessel, stop valves must be fitted on the delivery pipe, to prevent the return of the water when either or both pumps are not at work. The air vessel is of great importance, as it equalizes the flow of the water through the main, and less weight is required on the top of the plunger for the down stroke. The capacity of the air vessel should be about ten times the volume of water delivered by each stroke of the pump.

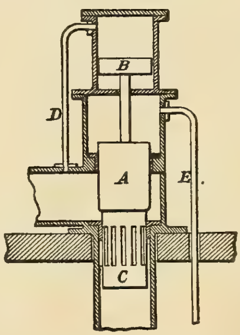


Fig. 143.—Relief Valve.

A, Solid plunger. B, Piston. C, Slotted pipe leading to reservoir. D, Pipe connecting the cylinder with the main. E, Waste pipe leading to the reservoir.

A relief valve should be placed on the delivery pipe to prevent undue pressure; it is fitted with a lever and weight. In some examples a solid plunger is adopted, having a piston and rod at the top, the piston working loosely in a cylinder connected to the main by a small pipe. The plunger A rises when the pressure increases, being larger at A than at C, and allows the water to flow through the slots into the

reservoir from which it is pumped, thereby relieving the pressure. The plunger falls again by gravitation, and the piston B, acting like a cataract, prevents the action taking place too suddenly.

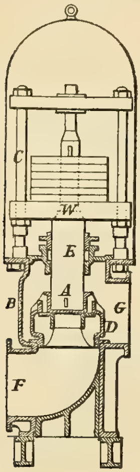


Fig. 144.—Pressure Valve.
A, Plunger. B, Valve chest. C, Guides. D, Valve. E, Stuffing box. F, Branch pipe from pump. G, Delivery branch. W, Weight.

The pressure valve is placed beyond the air vessel on the main pipe; its sole use is to prevent the plunger of the engine descending too rapidly in the event of one of the main pipes bursting. The example under notice consists of a plunger, loaded with a certain weight to suit the head of water; on the bottom of the plunger a double-beat valve is secured by a cotter, the valve working on a seat bolted down by bolts passing through it, and secured by lugs at the bottom of the bent pipe and nuts at the top bearing on the valve seat. At each stroke of the engine this valve is lifted, and consequently were a pipe bursting the engine has still the same duty to perform. As has been stated, a modification of these valves has been successfully used instead of stand pipes.

PUMPING ENGINES FOR DRAINAGE WORKS AND GENERAL PURPOSES.

THE LONDON DRAINAGE SYSTEM.

The Abbey Mills Pumping Station is the largest establishment of the kind on the Main Drainage Works, and provides, by means of eight engines, an aggregate horse-power of 1140, capable of lifting 15,000 cubic feet of sewage and rainfall a height of 36 feet per minute. Each of the eight engines is furnished with two boilers; and they are contained in a cruciform building, arranged in pairs, each arm of the cross containing two engines. The engines, as in all the other pumping establishments on these works, are expansive, condensing, rotative beam engines, but are somewhat more powerful than those used elsewhere, the cylinders being 4 feet 6 inches in diameter, with a stroke of 9 feet. The pumps differ also in being double-acting, a circumstance which admits of the air

pump, &c., being worked from the main beam, instead of from a

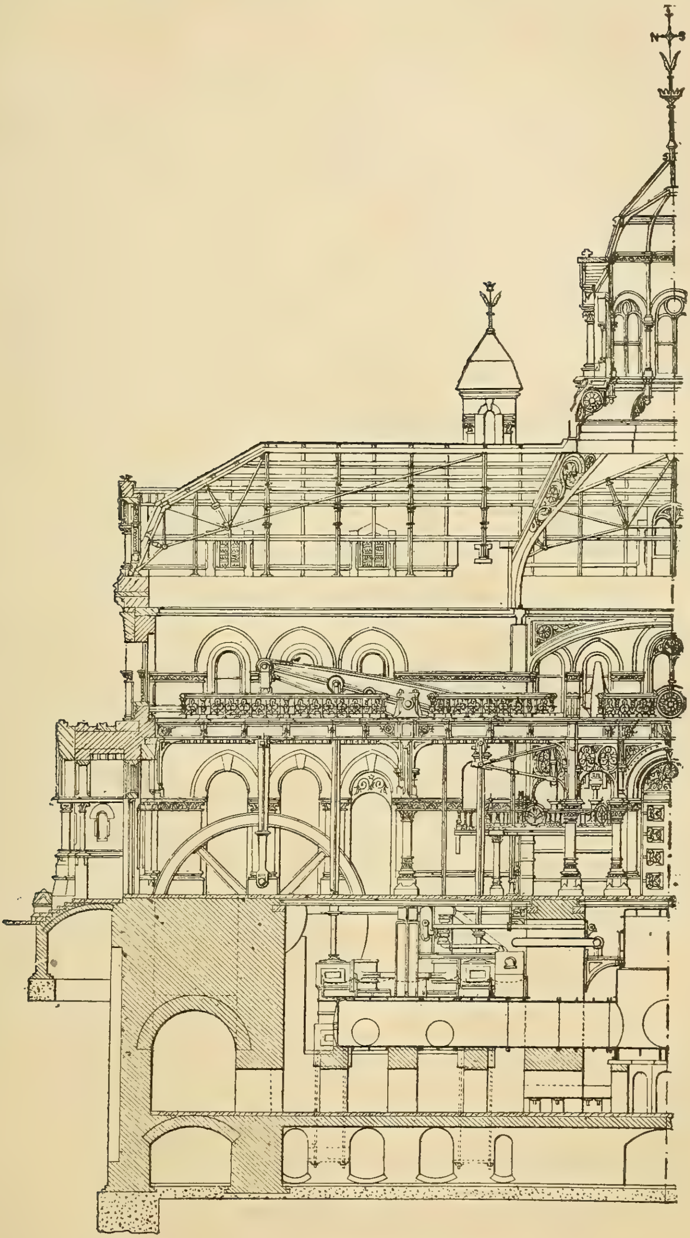


Fig. 145.—Abbey Mills Pumping Engines. One-half Elevation.

distinct beam, as at the other stations. Each engine works two pumps, having a diameter of 3 feet 10½ inches, and a length of stroke of 4½ feet. The boilers are each 8 feet in diameter and 30 feet long, with double furnaces.

The engine building is divided in height into three compartments, the lower one being the pump well into which the sewage is conveyed from the Low Level Sewer, the second forming a reservoir for condensing water, and the upper one containing the eight engines and platform overhead. The lower part of this building lies about 3 feet above the bottom of a thick stratum of clay, overlying a considerable thickness of sand with water, through which the foundations are carried by piling to a bed of firm gravel below. The boiler houses and other portions of the work are founded upon the clay stratum overlying the sand. As the deep foundations are situated in close proximity to the Northern Outfall Sewer, which is contained in an embankment above the general level of the ground, great caution was requisite to prevent any settlement in that sewer. The boiler house and coal stores are built between the outfall sewer and the engine house, so as to keep the deep excavations as far distant from the sewer as practicable. The coal stores are built with their floors level with the stoke holes in the boiler house, and tramways are laid from one to the other; this floor is only a trifle below the surface of the ground, which is 6 feet below high water. One side of the coal stores forms the front side of the boiler house. Tramways are laid from the top of the coal stores to the Abbey Mill River, adjacent to the works, where a wharf wall is built for landing coal and other materials.

The sewage from the Low Level Sewer, before entering the pump wells, passes through open iron cages, the bars of which intercept any substances likely to interfere with the proper action of the pump valves; and these cages when requisite are lifted above ground by proper gearing, and the intercepted matter is discharged into trucks. The sewage then passes into the wells, and is lifted by the pumps through the hanging valves into a circular culvert of cast iron, and then forced into any of the three culverts forming the Northern Outfall Sewers.

It is fortunate that these works were not projected in the year 1306, when coal was first introduced into London, and was regarded as so great a nuisance that the resident nobility obtained a royal proclamation prohibiting its use under severe penalties; for this

pumping station alone consumes about 9700 tons of coal per annum. The expense of pumping, however, cannot be regarded as a wholly additional item in the cost of drainage under the new system; for the removal of deposit from the tide-locked and stagnant sewers in London formerly cost about £30,000 per annum, and the constant flow kept up in the sewers by means of pumping must necessarily keep them freer of deposit, and so reduce the outlay for cleaning them.

The Deptford Pumping Station is situated by the side of Deptford Creek, and close to the Greenwich Railway Station. The sewage is here lifted from the Low Level Sewer, a height of 18 feet, into the Outfall Sewer. An iron wharf wall and barge bed, 500 feet long, has been constructed at the side of the creek, and is provided with a crane and tramways for landing coal or other materials. There are four expansive, condensing, rotative beam engines, each 125 horse-power, and capable together of lifting 10,000 cubic feet of sewage a height of 18 feet per minute. These engines are supplied by ten Cornish single-flued boilers, each 30 feet long and 6 feet in diameter. The cylinders are 48 inches in diameter, with a length of stroke of 9 feet. The pumps, two of which are worked by an engine direct from the beam, are single-acting plunger pumps, the diameter of the plungers being 7 feet, and the length of stroke 4½ feet: one pump is worked from the beam midway between the steam cylinder and the centre pillars, and the other midway between the centre pillars and the fly wheel. The air, feed, and cold-water pumps are worked by a separate beam attached to the cylinder end of the main beam. The pump valves are of the leather-faced hanging kind, and the sewage is discharged through them into a wrought-iron culvert placed on the level of the Outfall Sewer, with which it is connected by a brick culvert, which receives also the sewage from the High Level Sewer, previously brought by gravitation under the creek through four cast-iron pipes 3 feet 6 inches in diameter. Both streams enter the Outfall Sewer, and are conveyed to Crossness, where they are again lifted. The chimney shaft at this station is 7½ feet in diameter at the base and 6 feet at the top; its height is 150 feet, and the furnaces draw from the sewers and the engine-well to assist in their ventilation. The accommodation for coal is ample, the sheds covering an area of 18,000 feet. Gratings are used for intercepting the larger substances brought down by the sewers, in the same manner as at the other pumping stations.

The Crossness Reservoir and Pumping Station.—The sewage on the south side of the Thames is discharged into the river at the time of high water only; but the sewer is at such a level that it can discharge its full volume by gravitation about the time of low water. Its outlet is ordinarily closed by a pen stock placed across its mouth, and its contents are raised by pumping into the reservoir, which is built at the same level as that on the north side, and, like it, retains the sewage, except during the two hours of discharge after high water. The sewage is thus diverted from its direct course to the river into a side channel leading to the pump well, which forms the lower part of the engine building; from this well it is lifted by four condensing rotative beam engines, each 125 horse-power, working direct from the beam two compound pumps, each with four plungers. The cylinders are 4 feet in diameter, with a length of stroke of 9 feet; they are situate at the end of the main beam, which is 40 feet in length, the crank shaft connecting rod being attached to the farther end, and the pump rods situated on either side of the beam centre. The air, feed, and cold-water pumps are worked by a separate or counter beam, fixed at one end to a rocking lever, and attached at the other end to the main beam. The cylinders are supplied by twelve Cornish boilers, each 6 feet in diameter and 30 feet long, with an internal furnace and flue 3 feet in diameter, set so as to have the second heat carried with a split draught along the sides, and the third heat under the bottom of the boiler, into the main flue leading to the chimney. The maximum quantity of sewage ordinarily requiring to be lifted by these engines is about 10,000 cubic feet per minute; but during the night that quantity will be considerably reduced, and, on the other hand, it will be nearly doubled on occasions of heavy rainfall. The lift also will vary from 10 to 30 feet, according to the level of water in the sewer and in the reservoir into which it is lifted. These variable conditions led to some difficulty in the working, but which has been overcome by an arrangement of the pump plungers. The pumps, which are single-acting, are placed equidistant on each side of the beam centre, their cases being each 12 feet in diameter, and fitted with four plungers 4 feet 6 inches in diameter. These plungers are placed in pairs, each pair being worked from a crosshead on the main beam, which is in two flitches for this purpose, and either pair of plungers can be thrown out of gear. By this means the capacity of the pumps may be varied in the proportion of one, two,

or three, as the inner pair, outer pair, or both pairs are thrown out of gear. The sewage is discharged into a wrought-iron trough,

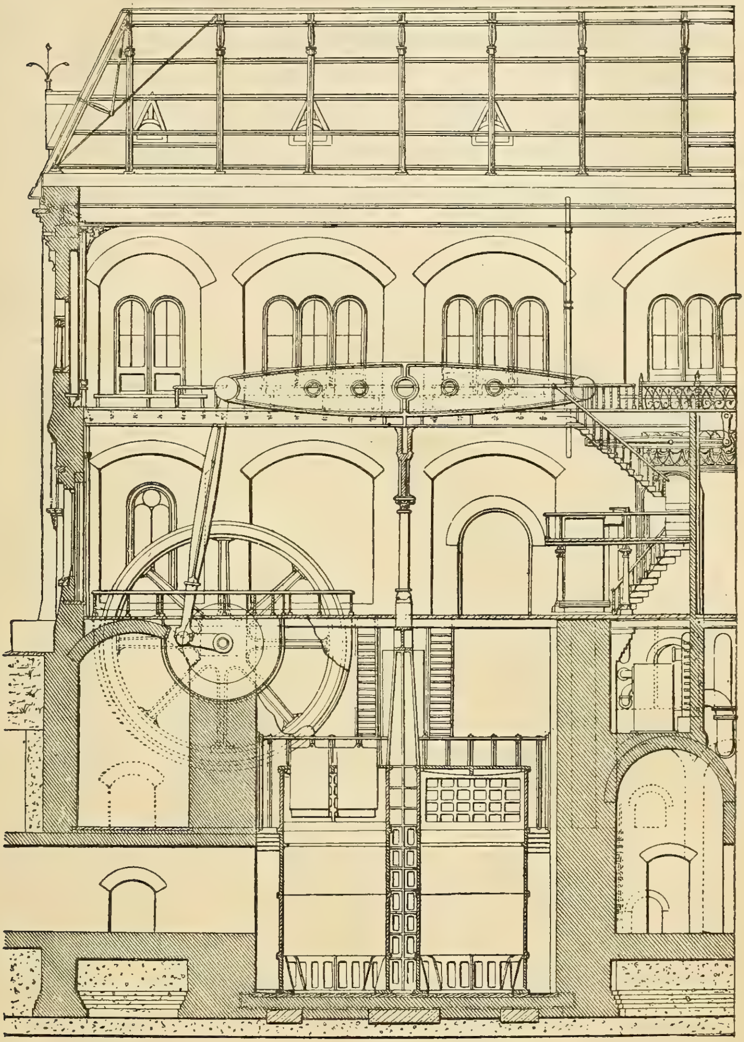


Fig. 146.—Pumping Engines at Crossness. One-half Side Elevation.

through hinged leather-faced valves, which are suspended from wrought-iron shackles, and fitted with wrought-iron back and front plates. Each valve is 12 inches by 18. As has been before stated, substances which might prevent the proper action of the valves are

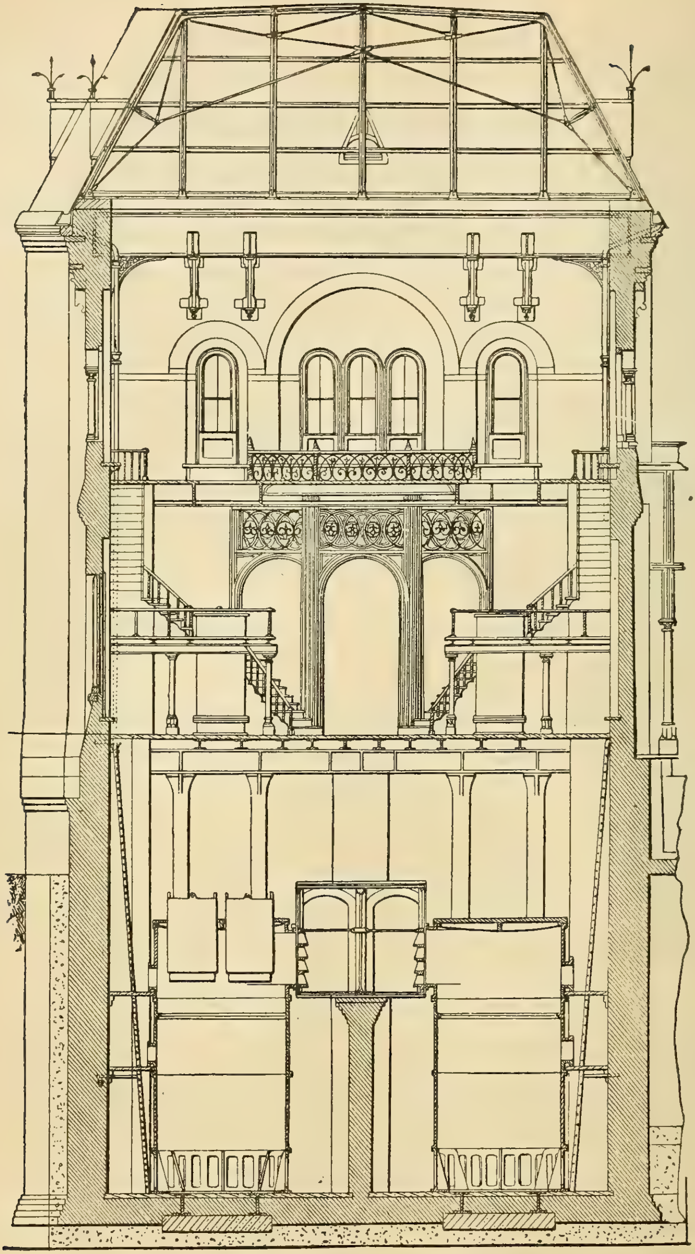


Fig. 147.—Pumping Engines at Crossness. End Elevation.

intercepted before reaching the pumps by a wrought-iron grating

placed in front of the openings to the pump well. Such substances are lifted from the face of the grating by an endless chain with buckets or scrapers and combs attached, working vertically in front of and close to the grating, the teeth of the combs passing between the bars. On the descent of the chain the buckets are overturned and discharge their contents into a trough, from which they are removed by manual labour.

The sewage, after being delivered from the pumps into the wrought-iron trough, is discharged through brick culverts into the reservoir, or, in case of need, provision is made for its discharge through other culverts directly into the river. After remaining in the reservoir until the time of high water, it is discharged by a lower

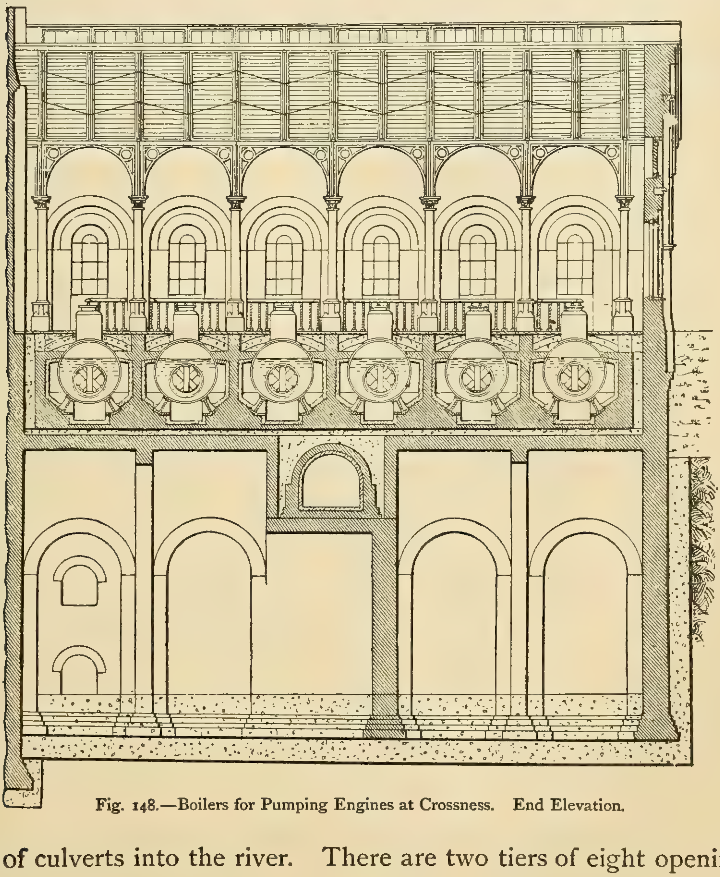


Fig. 148.—Boilers for Pumping Engines at Crossness. End Elevation.

set of culverts into the river. There are two tiers of eight openings in each compartment of the reservoir, the upper eight for the admis-

sion of the sewage from the pumps to the reservoir, and the lower eight for its discharge into the river. These apertures are all opened and closed by pen stocks.

The reservoir, which is 6½ acres in extent, is covered by brick arches, supported on brick piers, and is furnished with weirs for overflows, and with a flushing culvert. The height, level, and general construction are similar to the one at Barking Creek. Over the reservoir are built twenty-one cottages, for the engineers and other persons employed upon the works.

The ground upon which these works are constructed consists of peat, sand, or soft silty clay, and affords an insufficient foundation within 25 feet of the surface. To obviate the need of removing this vast mass of soil, and thereby reduce the expense of the foundations, trenches were cut down to the solid earth, and the culverts on the various levels were built as far as practicable in the same trenches, one above the other; the lowest, leading from the Outfall Sewer to the pump wells, support those discharging the sewage from the reservoir, and these again support those leading from the pumps into the reservoir. On account of the pump wells it was necessary that the walls of the engine house should be carried down to the depth of the gravel, independently of the nature of the ground; but such was not the case with the boiler house. The boilers and stokehole floor are supported on arches springing from walls built up from the gravel, and the space below the floor is made available as a reservoir for condensed water. The water from the hot and cold wells of the engines is conveyed hither, one compartment being used as a chamber for cooling that from the hot well, previous to its being used again for condensing water. With the same object of saving separate foundations, coal stores and workshops have been erected partly on the external walls of the reservoir and partly on the culverts in front of them; large coal stores being also provided in front of the boiler house and on a level with the stoke holes, into which the coals are brought on tramways. There is also a tramway for the upper-level coal sheds, on the level of the tops of the boilers, from whence the coals are shot into the stoke holes below. Tramways are also laid from the coal sheds to the river, where jetties are built for landing the coals. A wall has been constructed along the river frontage of the works for a distance of about 1200 feet, by which a large portion of the "Saltings" has been reclaimed. This wall is of brick, carried upon brick arches resting on piers formed

of iron caissons filled with concrete, which are carried down to the gravel.

The chimney into which the flues from the boilers are conveyed is square in plan externally, 8 feet 3 inches in internal diameter throughout, and 200 feet high; it is founded upon a wide bed of concrete brought up from the gravel, which is here 26 feet below the surface. The reservoir, the several culverts, and the pump wells are connected by flues with the furnaces of the boilers, for the purpose of ventilation, in the same way as at the Deptford and other pumping stations.

The outlet into the river from the Outfall Sewer of these works consists of twelve iron pipes, each 4 feet 4 inches in diameter, carried under the "Saltings" into a paved channel formed in the bed of the river. These pipes are connected with the Outfall Sewer by culverts in brickwork on the land side of the wall, the numbers of these culverts being gradually reduced and their dimensions increased as they approach the junction with the large sewer.

HIGH-PRESSURE GEARED PUMPING ENGINES.

Small high-pressure geared engines may be conveniently used for pumping water out of docks, and for other drainage purposes, being arranged for three pumps. The connecting rod runs from the cross-head of the piston rod, and works a cranked shaft, having a fly wheel at one side and pinion at the other, geared into a spur wheel keyed on a cranked shaft for the middle pump; one of the side pumps is worked from a pin let into one of the arms of the spur wheel, and the other pump is driven from a crank placed on the other end of the shaft. The engine is placed horizontally, and the pumps are vertically arranged against the side of the dock wall. When they are needed to pump the water out of a dock in course of construction, the engine is bedded on an overhanging wooden frame, having a strut let into the wall, or temporary pile foundation, on each side of the frame for carrying the engine and the three throw cranks for the pumps. The pumps are in some instances of the plunger type, having the plungers cast in brass; while others are simply lift pumps, fitted with valves of india rubber working on brass gratings. There is one suction pipe and one discharge pipe common to all the three pumps; the former has a three-branched pipe fitted to the top, to which are bolted the pumps, one to each branch; while the latter is

placed across the pumps, in communication with the valve chests, having one vertical delivery pipe placed at the end.

THE CENTRIFUGAL PUMP.

Centrifugal pumps have been much used for pumping water out of works in course of construction, and are recommended for their simplicity and the ease with which they can be applied to almost any situation. The pump, when placed in position, is driven by a belt from the fly wheel of a portable engine. This is a temporary arrangement; but many centrifugal pumps have been fitted up of a permanent kind, driven by wheel gearing. When the lift is of moderate height these pumps throw a vast body of water; and as they are not so liable to get choked with foreign matter, they may be used in many situations for pumping sewage with advantage.

Fig. 149 represents a pair of centrifugal pumps of the largest size for drainage purposes connected directly to the engines, a class of machinery brought to great perfection by the Messrs. Gwynne & Co. of London. This description of pump is admirably adapted for works of construction, water works, graving docks, &c., and more especially for drainage purposes, large tracts of land having been reclaimed by its aid. Where low lifts only are required it far eclipses the ponderous pumping engine of the beam type.

The construction of this pump is very simple. The revolving wheel or disc is formed of two concave plates, placed parallel with their concave surfaces towards each other. Two saucers, placed in corresponding positions, will give an idea of the arrangement. Between these discs is an arm or impeller, radiating from a boss or hollow axis, mounted on a shaft which works horizontally, vertically, or at any intermediate angle. This impeller, which regulates the distance between the discs, varies in breadth; its narrowest part is at the outer edge of the discs, becoming gradually broader until its edge intersects the inner surface of the openings for the suction. Its breadth is varied in such a ratio that the areas of any section cut from the wheel by the surfaces of circular cylinders, whose axes coincide with that of the shaft, shall be equal to such other section at any distance from the centre; and these areas are so arranged in order that the column of water or other fluid entering the wheel when in a state of revolution may have an uninterrupted flow from the centre to the circumference, and that the

quantity received and discharged may be constantly equal. This is considered to be essential when large bodies of water are to be discharged, or when high velocities are required. The inner surfaces of the discs, or the annular opening around the whole circumference,

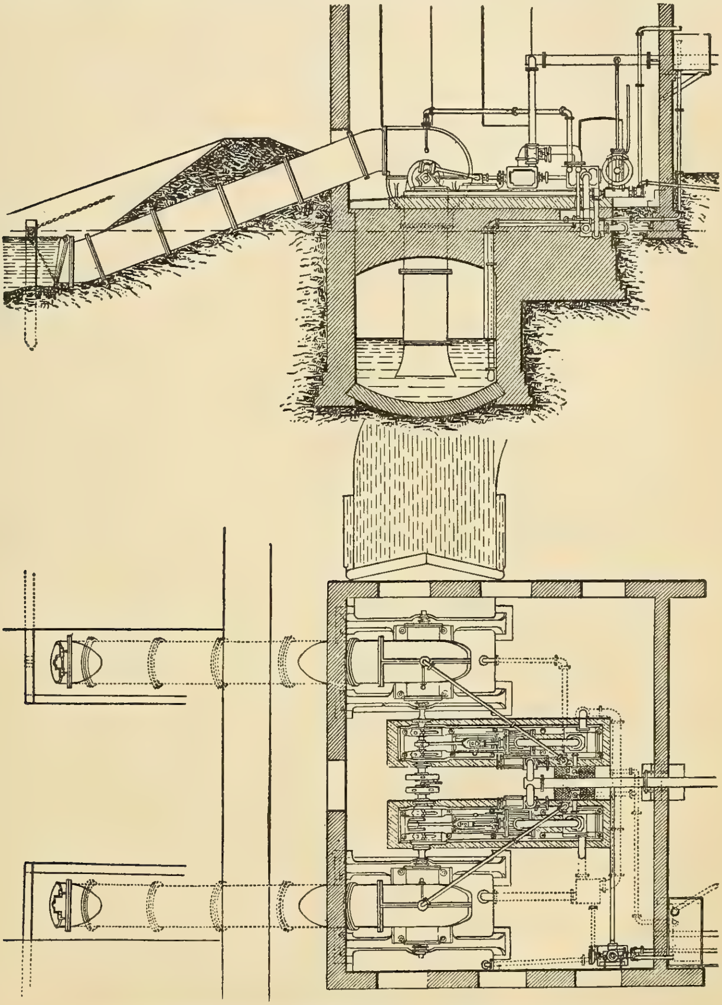


Fig. 149.—Arrangement of Centrifugal Pumping Machinery—Gwynne & Co.

has an area equal to the openings at which the water is admitted into the centre of the revolving wheel. There are two cylinders or water passages, one on each side, with a passage for each in connection with one suction pipe, rendering the pump extremely

compact. In one of the cylinder covers or ends there is a bearing supporting the spindle on which the wheel is fixed, in the other cylinder cover there are a gland and stuffing box through which the shaft for the revolving wheel passes. The suction pipe may, if desired, be run any moderate length horizontally, and the pump may be placed from 15 to 20 feet vertically above the water to be raised; in most cases it is advisable to have a foot-valve at the bottom of the suction pipe, so as to retain the water in the pump when standing still. The delivery pipes, as seen in Fig. 149, are fitted with self-acting flap valves, to prevent any water flowing back on to the land when the pump is not working. The pumps are fitted to discharge 30,000 gallons per minute, 12 feet high; the pipes are 42 inches in diameter; the engines are of the horizontal condensing type; diameter of cylinders 21 inches, length of stroke 21 inches.

The action of the pump is as follows:—The pump and pipes being filled with water, which the foot valve at the bottom of the suction pipe retains, the wheels or discs are coupled to the engine, and the latter being started at a high velocity, a centrifugal motion is given to the wheel, and to the water contained in the disc, which is driven out into the case or receiver of the pump. The partial vacuum thus formed in the disc is filled by the water forced up the suction pipe by the pressure of the atmosphere; the water entering the disc receives centrifugal motion in the same way, and thus a continuous stream is received into and discharged from the pump. To prevent the water from rotating in the case, and to give it a direction upwards to the discharge pipe, a stop or plate is placed at the base of that pipe, reaching to the joint between the piston and the case. The joints between the suction pipes and disc are so made that sand, mud, or gritty matter cannot lodge near them, by which means the wear is so reduced as to become almost imperceptible.

The following may be enumerated as the principal advantages of the centrifugal pump:—(1.) It can be erected easily and quickly. (2.) It works with an easy rotary motion, without valves, eccentrics, or other contrivances, which consume power in friction. (3.) It will discharge a quantity of water greater in proportion to the power employed than any other pump—75 per cent. being taken as an average. (4.) It is economical in use, and of very great durability—an important point in all machinery. (5.) It discharges a continuous and steady stream without air vessels. (6.) It is little affected by sand, mud, grit, or other foreign matter in the water,

which so rapidly destroy all other pumps. (7.) The large sizes will admit the passage of solid bodies 6 inches in diameter without injury, and the smaller sizes in proportion. (8.) It will pump hot or cold liquids equally well. (9.) It requires a very light and inexpensive foundation, as there is no vibration while working.

A striking proof of the great superiority of these noiseless machines, working at a high speed, over the beam pumping engine, may be seen in the draining of the Haarlem Lake. The weight of the pumps and valves attached to one of these latter engines was about 200 tons, the pumps were adapted to raise about 70 tons of water per minute a height of 15 feet when working their usual speed of eight or ten strokes; but a centrifugal pump of the above description, doing the same amount of work, will weigh only 5 tons.

The *Pulsometer Pump* has been recently introduced with good results in many situations where other forms of pump would have been more troublesome to keep in order. It is a steam pump without moving parts except certain valves. The operation consists in forcing water to a height by the direct pressure of the steam, and the lifting of the supply into the pump by the after condensation of the same steam; this is accomplished through the medium of a ball valve above and clack valves below, arranged in two vertical chambers.

WINDING ENGINES.

In modern practice the use of the flat hempen ropes with these engines has been discarded, in favour of the wire rope of a round form. The drums and pulleys for these ropes must be of large diameter, and the angle of the rope from the drum to the pulley on the pit-head frame should not be too acute. Where the weight lifted is about 1 ton, the thickness of rope will be about 1⅓ inch, and will weigh about 4½ lbs. to the foot, the diameters of drum being about 5 feet and 16 feet, and the time taken to lift through from 250 to 300 fathoms about 1 minute.

The engines used at collieries for winding purposes should be of the simplest construction, strong, and free from all unnecessary and expensive complications. With this view spur gearing has been discarded by many first-class manufacturers, although geared engines are still in extensive use: the object of using a pinion on the engine shaft working into a spur wheel on the drum shaft being to

reduce the diameter of the cylinder and length of stroke of the piston, and so to drive the engine shaft at a greater number of revolutions than the drum shaft. The old type of engine most in favour is of the beam description, vibrating on a gudgeon on pillow blocks supported by a single column, having plain cast-iron guides, with crosshead and link attachment connecting the piston rod with one end of the beam; this being the simplest arrangement for giving a true vertical motion to the piston rod. The other end of the beam is connected to the crank shaft by a cast-iron connecting rod, of sufficient weight to balance the piston and its adjuncts. These rods are fitted with wrought-iron straps and brass bushes, with jibs and keys for adjusting the brasses. The bed plate for carrying the cylinder, main column, and pillow block for the crank shaft is cast in one piece. When the bed plate is securely bolted down on an even surface, with a firm foundation, this form of engine is very strong and durable, and is generally constructed on the high-pressure principle. Horizontal geared engines, however, have in a great measure superseded those of the vibrating beam type. They are certainly very compact, and when properly proportioned give great satisfaction, notwithstanding the objections arising from their wheel gearing.

The DIRECT-ACTING HORIZONTAL ENGINE, with the drum for the wire rope placed on the crank shaft, may be regarded as the type of engine to be used for the future. Simplicity is the object to be attained, and we attain it in the direct motion of this engine simply by giving a little more diameter of cylinder and a longer piston stroke, with a certain number of revolutions to suit the diameter of the drum and the speed usually allowed for running the wire ropes. Although single engines are in daily use, they are better to be used in duplicate, with one crank shaft, and cranks at right angles to each other. With the latter form there is no difficulty in starting, as is sometimes the case with single-cranked engines, which have a tendency to stop on the dead centre, or extreme end of the stroke, and require great attention on the part of the attendant to prevent this occurring. This objection is entirely removed by coupling the engines at right angles, the one assisting the other in the extreme position. The perfect ease and certainty with which these engines can be handled by means of the beautiful link motion and double eccentrics—combined with the powerful brake on the periphery of the fly wheel—renders the direct-acting horizontal engine a great boon to the practical miner.

The *cylinder* for these engines is a plain casting, with steam and exhaust ports suited for the ordinary slide valve: one steam port at each end, and a central port for the exhaust. It is preferable to fit a cover at each end, more especially for large diameters, as the boring bar requires to be of a large size to bore out truly these long

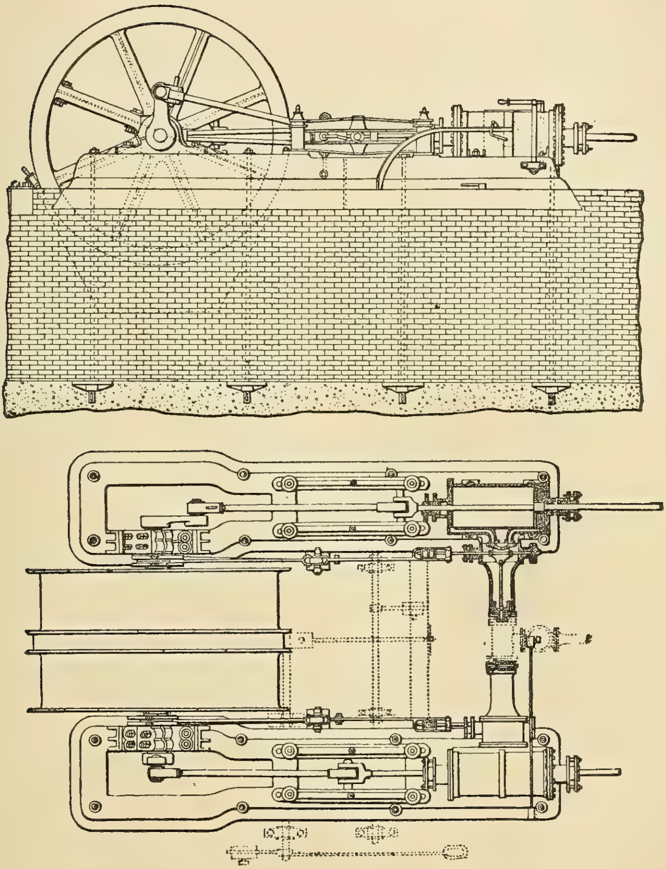


Fig. 150. - Colliery Winding Engines. Side Elevation and Ground Plan.

cylinders free from vibration, and the hole for the bottom bush in the stuffing box on a solid end is too small in diameter for an ordinary sized boring bar. There is a deep stuffing box on each cover, fitted with a gland in the usual manner. The piston rod passes through both these boxes, an arrangement which takes part

of the weight off the piston on the end glands, the piston rod acting as a round beam loaded at the middle when the piston is at half stroke; by this means the action of the piston has not so much tendency to wear the cylinder oval. Trunks or hollow pipes have been introduced in some classes of blowing engines to remedy this evil, inherent in all horizontal engines of very large size; and when properly proportioned they have given good results. The cylinder is cast with brackets on the bottom half for bolting it down on the bed plates; of course these palms or brackets should be nearly in a line with the strain, or a little below the centre line of the cylinder. Joggles are cast on the bed plate to embrace the brackets, and by this means end keys are fitted and driven in tightly, thus taking the shearing strain off the bolts. By attention to these details secure and firm work is obtained, more especially for high-pressure engines, where the succession of shocks from the high steam pressure used has a great tendency to shake the cylinder and loosen the fittings if not properly joggled to the bed plate. Indeed, for fast-going engines of the high-pressure type, the repeated shocks received on the end of the cylinder necessitates the use of wrought-iron stays to bind the cylinder and bed plate firmly together; some makers even casting the cylinder along with the bed plate, which effectually secures this object.

The *steam valve* is an ordinary D one, and should be fitted with packing rings on the back, bearing on the valve-casing cover. Some makers, however, prefer a small piston working in a short cylinder placed on the valve-casing cover, the piston being connected to the valve by means of a vibrating link. Some such contrivance is absolutely necessary to take the back pressure off the valve; and the former method does so by reducing the area on the back of the valve—that is to say, the rings are made steam tight, and the surface exposed to the steam in the casing is reduced; while by the latter method the valve is drawn, as it were, off the face with a certain force applied by means of the piston, and which being received on the pins of the vibrating link, renders it comparatively easy to move the valves by hand, just as any heavy weight is easily moved when suspended by a chain. The valve casing is sometimes cast on the cylinder; but many prefer it to be separate, and secured with bolts, as in this case the facing for the valve is more readily planed, and afterwards scraped to a true surface. The usual stuffing box is cast along with the casing, with brass bush and

gland, and it should have a brass guiding socket at the other end for taking the valve spindle, which passes through a tube cast along with the valve, and to which it is secured by means of a nut and jam nut at each end. Some makers dispense with this guide, and attach the rod to the valve by a screwed part at its end, having a nut let into the valve, with a jam nut to lock it securely when the valve is properly set.

The valve is actuated by double eccentrics and link motion. The eccentric sheaves are of cast iron, of the usual construction, and may be cast all in one piece, or have the means of taking them off the shaft without disturbing the main parts of the engine. The straps should be cast in brass, or they may be forged on the eccentric rods, and lined with strips of brass rivetted on. The link, suspension rods, weigh shaft, and reversing handle should be made of wrought iron, and all the working pins case-hardened; and the sliding block for the link should be of steel. All the bearings for the weigh shaft should be bushed with brass, and the whole motion adjusted in a strong and substantial manner.

The *starting handle* should be a plain lever, fitted with quadrant and catch for holding the link in position. The starting platform should be placed so as to command a good view of the pit head. Its position depends, of course, on the method of fitting up the machinery, but in ordinary cases the platform may be arranged at the back of the winding drum, and of sufficient height to see well over it. In this position, when the fly wheel is placed at the centre of the engine shaft, the friction strap and hand gear for working it is greatly simplified, and the attendant has the two important handles for reversing and applying the friction brake in a direct line with the pit head. The handle for working the stop valve of the equilibrium type should be placed here likewise, on the centre of the steam pipe between the two engines. The handles are, however, at times arranged on the outside of the left-hand engine looking towards the pit head, with a cross shaft, as in the former method, for the reversing gear placed underneath the bed plates or above them, supported at the end and middle with suitable pillow blocks. On this shaft the lifting arms are fitted, with a weight arm at the centre of the shaft, or between the end and middle pillow block, having a suitable weight, which may be placed on the starting handle, for balancing the links and rods, and thus easing the labour of starting and reversing the engines. The handle will of course

suit almost all attendants when arranged for the right hand. The lever for the brake is worked by foot; it should be of great length, and so placed that the attendant can press it with his left foot whilst he holds the reversing handle. The brake lever must, of course, be arranged horizontally, and fitted with a cross shaft and short lever at the end for taking the brake strap of wrought iron lined with blocks of wood. The shaft is supported on three pillow blocks, and is fitted with a weighted lever, the weight being sufficient to balance the long foot lever, which should have a suitable stop to keep it always at a convenient height for treading upon. Many engineers are of opinion that it would be better to fit a hand lever and rod to the long brake arm, instead of pressing on it with the foot; but it must be borne in mind that both hands may be required at times to lift or depress the link motion, and the foot can be applied to the brake when the engine requires to be suddenly stopped. In other examples the long brake handle is placed above the floor of the engine room, the engineman moving it by hand, and the handle is kept up by a catch cast on a suitable cast-iron column: there is another catch placed on a nut worked by a screwed rod and wheel, supported by the column. The nut can be adjusted at pleasure to suit the wear of the wooden friction blocks. When the handle is depressed and sprung under the catch the blocks are pressed against the friction wheel, and when the friction requires to be increased the wheel on the screw rod is turned by hand, which firmly locks the friction blocks.

The *piston* for all horizontal engines should be of the strongest and lightest construction possible, fitted with a single packing ring, and the usual junk ring. The packing ring may have steel springs between it and the body of the piston; but some makers prefer a plaited gasket. The junk ring is bolted to the piston with screwed bolts and nuts recessed in the body of the piston. Another form of piston largely used for high-pressure engines is a plain casting, turned on the rubbing surface, and recessed for light steel springs. This is certainly the simplest form of metallic packed piston; and when it is supported by means of the piston rod passing through stuffing boxes at each end of the cylinder, it works admirably even for large diameters. The method of connecting the piston to the rod is by forming a coned part at the middle of the rod with a corresponding cone turned in the piston, which is secured by a cotter passing through the body of the piston, as in the ordinary

packing-ring system; but when the piston is cast solid, and indeed for all pistons, it is preferable to cut a screw on the rod at the small end of the cone, which is fitted with a nut for pressing the piston firmly on the cone; and to prevent the piston turning round in the cylinder, as it may do in course of time, a small short key is let into the rod, having a corresponding part cut in the piston for its reception.

The *crosshead* and *gudgeon* for the connecting rod is of wrought iron, suited for single or forked ends as may be desired; the hole in the crosshead for the piston rod is bored out slightly tapered, the rod being turned to suit, and secured with a cotter passing through them both. Holes should be drilled at the small end of the cotter for passing a split pin through, to keep it from shaking loose. The holes for the gudgeon in the jaws of the crosshead are bored quite parallel, and the gudgeon, being accurately turned, is driven through tightly, and secured with a key. The gudgeon can be of a less diameter at the ends for taking the guide blocks, and of sufficient length at one end for fitting the eye of the feed-pump plunger to it.

The *motion bars* for guiding the crosshead in a direct line with the piston rod are of cast iron. The bottom bars are generally cast along with the bed plate, but they sometimes form separate castings, which require to be fitted to the bed plate; while the top bars are generally made—so that the gear can be adjusted—with thin strips of metal between them and the bottom bars, which can be reduced in thickness as the guide blocks wear. In this arrangement the top bars are secured to the bottom ones with bolts at the ends, the same bolts securing the bottom bars to the bed plate; but in some cases the bottom and top motion bars are cast in one piece, and fitted and bolted down on the bed plate. These guiding bars must be accurately planed, and also the guide blocks, which are cast in hard brass. Sometimes cast-iron blocks are adopted, in which case the rubbing surfaces are filled in with white metal, recesses being left in the casting for that purpose; plain cast-iron blocks, however, answer very well, when lubrication is properly attended to—that being a most important point in all rubbing surfaces. Oil cups should be cast on the top motion bars, and fitted with proper covers to exclude grit, with siphon pipe and wick to supply the oil drop by drop.

The *connecting rod* is of wrought iron, turned from end to end, with oblong pieces at the ends accurately planed, and fitted with

wrought-iron straps and jibs and keys for adjusting the brass bushes; suitable lubricating cups are fitted to the straps.

The *main cranks* are of cast iron, but most engineers would prefer them of wrought iron, as they are much stronger and better adapted for engines subjected to severe shocks. They are usually bored out and shrunk on the shafts hot; but when they are forced on cold with an hydraulic ram the material is not so much strained, while the holding power is equally good. The cranks are further secured with a single key, fitting into a recess planed in the shaft and slotted out in the crank eye. The crank pin is slightly tapered in that part fitting into the hole in the crank, and is forced on and then rivetted at the end, a part being turned out for this purpose; this makes very secure work. In some recent examples the cranks are formed of discs of cast iron, with a side flange on the circumference of the disc, strongly ribbed to the boss at the centre. This plan balances the engine better than the single crank arm. The crank pin is secured by means of a nut and feather or key on the pin.

The *main pillow blocks* are separate castings, fitted with brasses, and caps arranged at an angle, so that the brasses are adjusted in the direction of the greatest strain. The bottom of the blocks are planed, as also the fitting strips on the bed plate, which has extra strong joggles cast on it for driving in wedges, thus taking the shearing stress off the pillow block holding-down bolts.

The *bed plate* is a strong frame of a box section, open at the bottom; it is tied at the ends and at the middle in the casting, and should be strengthened with cross feathers between the sides, having all the necessary joggles and fitting strips for the cylinder, pillow block, pumps, and other minor fittings. There should be at least four large holding-down bolts on each side of the frame, passing down through holes left in the foundation, and secured on the under side with a plate and key for each bolt. The foundations should contain suitable man-holes, so that these bolts can be adjusted at any time. In some instances the plates at the bottom of the foundation are carried across, embracing two bolts; by this means a foundation of brickwork laid in cement is firmly bound from top to bottom. When brick is used for the foundation it is preferable that a layer of stone-work or balks of wood be placed on the top, for the main bed plate to rest on.

The *main shaft* of the engine should be of wrought iron, and all

the bearings and raised parts for the drum, fly wheel if so fitted, eccentrics, and other minor details, should be accurately turned; while all the eyes of the various fittings should be bored out to the exact size, and held by means of keys bearing on a flat part of the shaft, keyways being cut in the parts. This is by far the cheapest and best mode of hanging the drum and centre pieces, fly wheel, &c.; the old mode of hanging these fittings with a number of keys in each is not to be commended, and has now become obsolete.

The *feed pump* is of the plunger type, and is bolted down on the top of the bed plate at the end nearest the main crank shaft. It is desirable that the plunger should be of brass or Muntz metal, connected by means of a wrought-iron rod to the end of the gudgeon for the crosshead—an eye is forged on this rod, and accurately bored out to take the end of the gudgeon, and held in position with a set screw. When the pump is placed well back, the plunger is better balanced at the extreme IN stroke, as there is a considerable distance from the pump gland to the centre of the crosshead while in that position; and the plunger by this arrangement is not so liable to droop, as it would do were the crosshead working quite close up to the pump gland. The suction and delivery valves and seatings are of brass, fitted into cast-iron valve chests; an escape valve should also be fitted, loaded with a certain weight, so that when the attendant shuts the feed valve on the boiler, the water is forced past the escape valve, and finds its way by a pipe connection into the pond or cistern from which the supply is drawn. An air chamber should be fitted to some convenient part of the feed pipe, as by this means the flow is more uniform, and tends to lessen the vibration in the pipes when the engine is working at full speed. As these pipes are sometimes subjected to the influence of hard frost, the engine rarely going all night, they should be properly clothed and protected with a non-conducting material; and a small plug tap should be fitted, so that all the water may be run off between the pump and feed valve placed on the boiler: these precautions taken, there is no fear of breakage occurring, as has too often been the case otherwise; for when an engine is started in the morning with the water in the feed pipe frozen a fracture must take place. In many arrangements the feed pump is dispensed with, the boilers being fed with a separate steam pump. The steam pipes must also be protected with felt and canvas sewn over, to prevent condensation. The exhaust pipe (when the waste steam

is blown up the chimney) should be trapped at the end, by leading it into a cast-iron cistern, fitted with a separate pipe into the chimney, having a bend at the end for directing the waste steam vertically; by this means much of the moisture is got rid of, being retained in the cistern and run off by a suitable overflow pipe. In this way the chimney is kept comparatively dry, and consequently less liable to the deterioration caused by a blast of steam and water blown into it. Some engineers prefer blowing off the waste steam directly from the cylinder by a vertical pipe passing through the roof of the engine house. By such an arrangement there is, of course, no steam blast to injure the chimney; but, on the other hand, we lose its valuable aid in urging the fires, by causing a partial vacuum in the chimney, which tends to supply through or between the fire bars the necessary quantity of oxygen to effect complete combustion.

The *drums* for the round wire ropes must be of large diameter. They are of two kinds, conical and parallel; with the conical the strain on the engines is better regulated. The lift is taken on the smallest diameter, and the rope unwinds for the empty cage from the largest diameter; consequently the latter balances in a measure the ascending cage fully loaded, which is lifted slowly, throwing less strain on the machinery. The drums are constructed of light cast-iron wheels, each with eight strong arms, and arranged for bolting together in two halves; a side flange is cast on to receive the wooden battens, to which they are securely bolted. For the conical drums there are two wheels of the same diameter, one at each end, with flanges bevelled according to the hollow given to the cone, and a smaller wheel is placed between them, having a flat rim; the wood is laid quite flat on the inside, and for the outer diameter it is cut to the cone required. The wire ropes are put on one above and another below the drum, and are wound from its longitudinal centre, the cone increasing to the ends at each side. The side and middle sheaves are keyed on the shaft similarly to an ordinary fly wheel, and should be fitted with wrought-iron rings, shrunk on the outer circumference of the bosses. It is preferable to fit a fly wheel close up to the main bearing; it should be of sufficient weight for the engine, and made of extra strength in the arms, as the brake is generally applied on the periphery.

The most approved form of *brake* consists of wooden blocks fastened to wrought-iron hinge pieces, vibrating on pins and joints,

secured to the floor in the fly-wheel pit. There are two fitted under the wheel at each end. On the vibrating centre or fulcrum of the long brake lever, a shaft carried on suitable bearings has a double-ended short lever keyed on it, fitted with eyes and pins; from these joints two side rods pass along, one on each side of the fly wheel, and are secured to eyes on the wrought-iron pieces for taking the friction blocks. Both brakes are so fitted, and with a movement of the long lever the off-brake is drawn against the periphery of the fly wheel, while the near one, fitted with short rods, transmits a compressive strain, which of course the short connecting links are better calculated for. With parallel winding drums the arrangement is somewhat different. The drums have two side sheaves for each; the two centre ones are placed sufficiently wide apart to take a strong ring which is fitted to the skeleton sheaves, this serving as a brake wheel, which in this arrangement is acted on by a strap lined with wood placed underneath it, fitted with suitable levers and shafts. Some authorities consider that this brake wheel is not so well placed as in the former example, for the strain acting on the centre of the shaft between the two engines tends to throw undue stress on the shaft. But we must not lose sight of the fact that when a separate fly wheel is used, placed at the side of the drum, the adjoining bearing has more duty to perform, and it may be concluded that with extra strength given to the shaft, to resist the pressure of the brake, the intermediate brake wheel can be used with advantage, equalizing the wear on the bearings, which is an important consideration in coupled engines.

In some examples where steam pumps are fitted, instead of the usual feed pumps, thus simplifying the engine considerably, the feed water is heated in its transit to the boilers by passing through a number of small tubes fixed in plates, inclosed in a cast-iron cylinder; the exhaust steam enters this cylinder, surrounds the tubes, and transmits its heat to the cold water passing through them. Some engineers blow the exhaust steam into a receiver, and the cistern placed at the end of the exhaust pipe for collecting the condensed water is a similar contrivance: the steam is blown over the surface of the water, which becomes thoroughly heated. Of course the steam that is not condensed is blown up the chimney in either of those feed-water heaters. In the former plan there is no trouble attending the operation, as the feed water is simply passed through the small tubes in its transit from the feed pumps; but the latter

requires attention to keep the water in the cistern at the proper level, and in many situations the water would require to be raised by a sèparate pump, or the cistern placed low enough to admit of the water running in from an adjoining pond.

We give a Plate of a Winding Engine of approved construction, erected in 1881 for a pit belonging to the Benhar Coal Company, at Niddrie near Edinburgh.

BLOWING ENGINES.

OVERHEAD-BEAM BLOWING ENGINE.

We will now consider that form of engine used for blowing air to the furnaces for melting iron ores, technically termed the "blowing

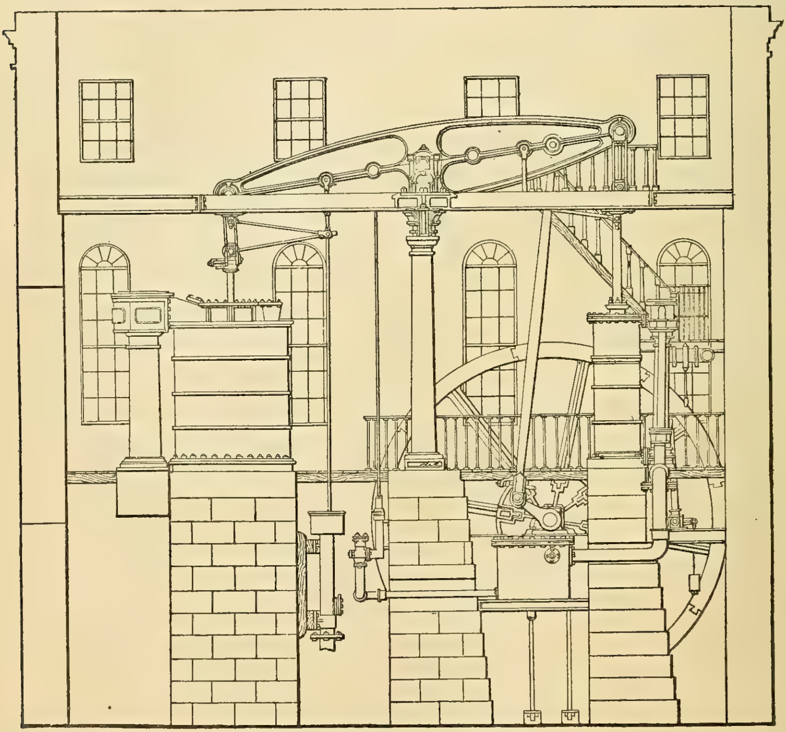
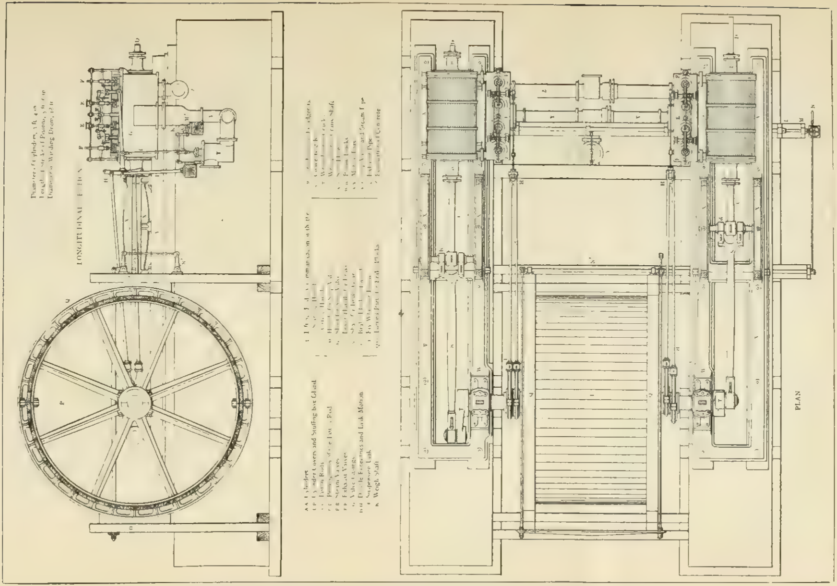


Fig. 151.—Blowing Engine. Side Elevation.

engine." This engine delivers the air into a receiver, the pressure varying from 2 to 4 lbs. per square inch, or a mean of say $3\frac{1}{4}$ lbs., that being the pressure on the large piston of the blowing cylinder.

WINDING ENGINES.



WINDING ENGINES, WITH DOUBLE ECCENTRICS, LINK MOTION, AND TAPPET VALVE GEAR.

ERECTED IN 1881 BY MESSRS. GIBB AND HOGG, AIRDRIE, FOR THE BENHAR COAL COMPANY.

A variety of forms of blowing engines are now in use, viz. the beam, the side-lever, the vertical, and the horizontal, which we will notice in succession.

The *high-pressure beam engine* has been largely used for blowing purposes. Its main beam is cast in two halves, held together by distance pieces; the steam cylinder is placed at one end of the beam, and the blowing cylinder at the other. The connecting rod and crank shaft are placed between the steam cylinder and the main centre of oscillation of the beam, and the cold water and feed pumps between the blowing cylinder and the main centre of oscillation.

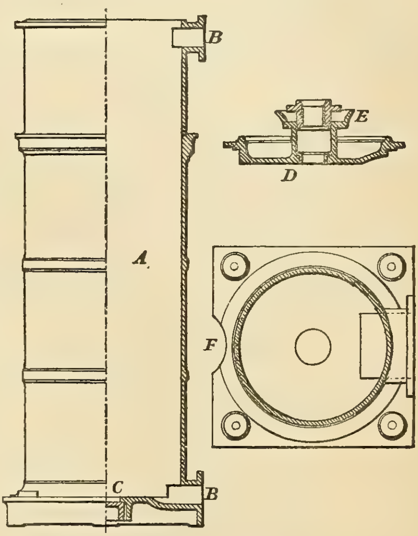


Fig. 152.—Steam Cylinder and Cover.

A, Cylinder. B B, Steam ports. C, Cone plug. D, Cover. E, Raised lip on flange for catching the oil. F, Part cut out for the connecting rod.

The *steam cylinder* is a plain casting, with oblong branches at the top and bottom for the steam ports, which are made as short as possible. When the stroke of the piston is long it is desirable to have the steam valves so arranged that the cubical capacity of the passages on the cylinder side should be as small as practicable, by which means much steam is saved at each stroke, as compared with some arrangements where the passages extend from the top to the bottom of the cylinder. A square base is cast along with the cylinder, having a hole in the centre for the boring bar to pass through, which is afterwards filled up with a plug or cover. Part of the base is hollowed out on the opposite side from that of the steam ports, to give the necessary clearance for the main connecting rod. The body of the cylinder has suitable belts cast on, and also a projecting moulding near the top for supporting the platform. The cylinder is firmly bolted down at each corner of the base plate with long bolts, passing down through holes left in the foundations, and secured at the under end with plates and cotters; these beam plates extend across the structure from hole to hole. A cast-iron

plate is laid down on the top of the foundation, having fitting strips for correctly adjusting the vertical line of the cylinder, corresponding strips being left on its base for that purpose. This makes a thoroughly good fixture, as these foundation plates spread over a large surface of the stone or brick work, and the action of the steam in the cylinder and motion of the working parts have not so much tendency to abrade the stone and loosen the foundations. The cylinder cover is generally an open casting, and should be turned on the face; the surface is made steam tight by scraping the faces on the cover and cylinder, and interposing a thin coating of red lead at the joint. A brass bush is fitted at the bottom of the stuffing box, and also in the cast-iron gland. The flange of the stuffing box has a raised part round the edge, to prevent the oil or other lubricant from flowing over and dirtying the cover. The cover is turned all over the exterior, and should be finished bright, as it is then much more easily kept clean. The bolts for the gland should be cut with a square thread, and have square nuts, as hexagonal nuts are not nearly so good for parts requiring such frequent adjustment.

The *piston* is of the usual description, and made very heavy;

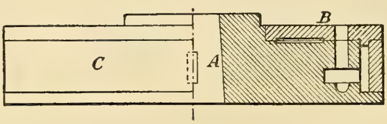


Fig. 153.—Piston for Steam Cylinder.

A, Coned part for the piston rod. B, Junk ring. C, Metallic packing ring.

indeed, some engineers cast the body solid, with a view to balance the large blowing piston at the other end of the beam. The packing ring should be in one piece; some use two rings, but this is not required, and is decidedly objectionable, from the fact that there are then four faces to be kept steam tight, whereas with one ring there are only two. The narrow junk ring is accurately turned on the fitting strips and corresponding parts on the piston, and is made steam tight by scraping the surfaces. The holding-down bolts are screwed into nuts recessed into the body of the piston in the usual manner. The piston rod is secured to the piston by means of a coned part turned on the former, with a corresponding cone on the latter, through which a cotter passes and tightly forces the piston on the coned part of the rod. A better plan is to fit a nut on the

top of the piston, having a screwed part on the piston rod, in which case a recess needs to be left in the cylinder cover for the nut to pass into, as the piston works closely up to the under side of the cover and down to the bottom of the cylinder, ¾ inch of clearance being quite sufficient between the piston and the end of the cylinder at the top and bottom.

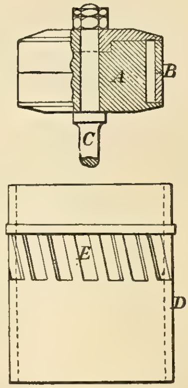


Fig. 154.—Piston Valve and Cylinder.

A, Piston valve. B, Metallic packing rings. C, Valve rod. D, Cylinder for valve. E, Slot holes.

The *valves* are of the piston description, fitted with metallic packing rings and junk rings, similar to the main piston; and they work in short cylinders placed in the nozzle chest and bolted to the main cylinder. These cylinders are cast with oblong ports, the bars lying at an angle; by this means the rings on the valves work more evenly, and are not so liable to form ruts as they would be were the bars placed vertically. These valve cylinders are properly secured in the casing, which is bored out for their reception. Each valve is connected with a rod passing through the centre of the piston, and secured with a collar on the rod and a screwed part fitted with a nut.

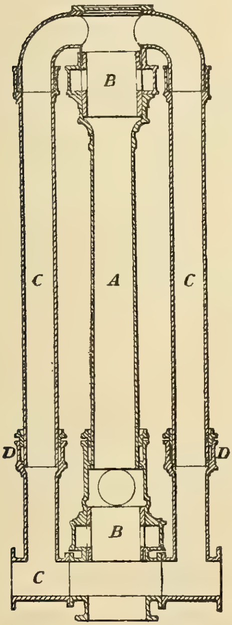


Fig. 155. — Nozzle Chest for Steam Cylinder.

A, Steam pipe. B B, Valve cylinders. C C, Exhaust pipes. D D, Expansion joints.

The *nozzle chest* is arranged with one central pipe, fitted with an expansion joint, and branch pieces at the top and bottom for bolting to the branches on the main cylinder of the engine, as well as with the main steam branch located at the top, so placed as to pass well under the beams for supporting the platform. The steam from the boiler is admitted into the central nozzle between the valves, while the exhaust takes place on the top edge of the top valve and the bottom edge of the bottom valve; the steam from the top passing through pipes on each side of the central pipe, which are likewise fitted with expansion joints. The exhaust steam from the top

of the cylinder passes down these pipes on each side, and they are connected to a cross pipe at the bottom, which carries away the steam from both ends of the main cylinder. Two branch pieces are generally cast on the cross pipe, for the convenience of carrying away the exhaust on either side, as may be determined on; of course one of them has a blind flange when completed. A cover is fitted to the top nozzle chest, and one to the bottom chest, the latter having a short pipe turned on the exterior surface.

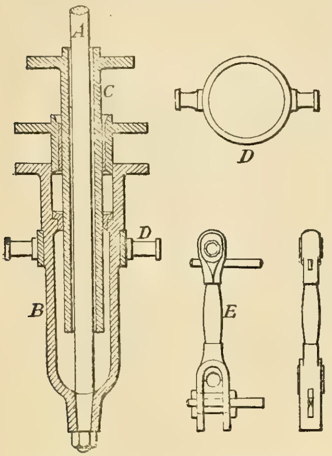


Fig. 156.—Stoup and Links for Valve Motion.
A, Valve rod. B, Stoup. C, Guide pipe. D, Strap. E, Side link.

The *valve spindle* passes down this pipe, and is connected to a solid end on another pipe (technically termed the *stoup*), by means of a coned hole on the end of the pipe and a corresponding cone turned on the valve spindle, fitted with a nut on the end of the rod. On the top of the stoup a stuffing box and gland is arranged, which makes it steam-tight on the pipe that is bolted to the cover. A wrought-iron strap with two side pins is fitted on the stoup; these pins take side rods passing downwards to the pins on the levers of the weigh shaft.

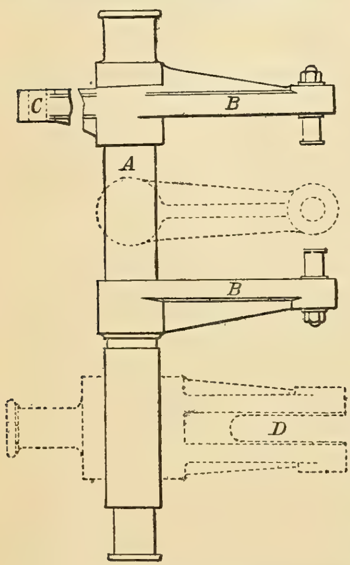


Fig. 157.—Wiper Shaft and Levers for Valve Motion.—A, Wiper shaft. B B, Levers for valve. C, Balance lever. D, Eccentric lever.

The *wiper shaft* is supported at both ends on bearings, and is fitted with a strong cast-iron lever, having a pin for taking the eccentric rod, with other two levers for the rods connected to the stoup for working the valves. A back balance lever, fitted with a suitable weight for balancing the valves, is also provided, and this is cast along with one of the levers for the stoup connection; while a socket is left on the double

lever for the eccentric rod for the starting handle. These levers should be made very strong and well feathered, and may be cast along with the shaft, at least those for the stoup and balance weight, but the eccentric lever should be made a separate casting for adjustment. As the strain is light a cast-iron shaft and levers may be adopted, when the weigh shaft is placed under the floor of the engine house out of sight; but a preference ought to be given to wrought iron in all valvular arrangements, as the material is better adapted for any sudden strain, even although balance valves are adopted.

The valves are actuated by means of an *eccentric and rod.* The

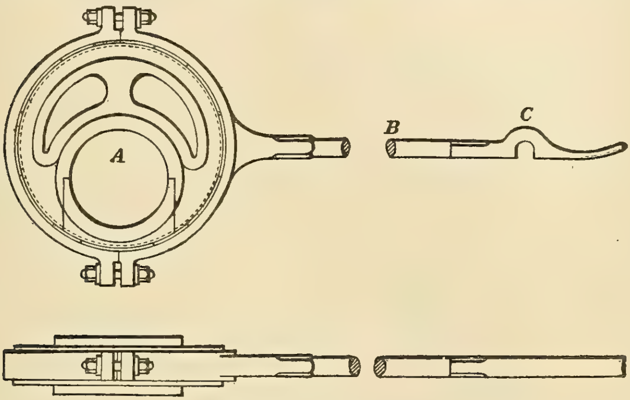


Fig. 158.—Eccentric and Rod.

A, Eccentric sheave. B, Eccentric rod and strap. C, Gab end.

eccentric sheave is so arranged that it can be put on and taken off the main crank shaft without disturbing any other detail, and is secured on the shaft with a key, as these engines only require to be worked in one way. The eccentric rod is of wrought iron; one-half of the strap is forged on with suitable lugs, and the other half has lugs forged on for bolting the hoop together, with a single bolt and nut for each lug. The rubbing surfaces are of brass, rivetted to the strap, and then accurately turned to suit the sheave. The lugs on the strap do not fit closely together, so as to adjust at any time the rubbing surface. Suitable mechanism for lifting the eccentric out of gear when starting the engine should be arranged. This may be worked in a variety of ways; with hand levers, or with a foot lever and rod attachment, which the attendant can press

on with his foot while his hands are free to move the steam regulating valve and hand lever, which is placed in a socket on the gab lever secured to the weigh shaft. This valve gear and mechanism for working it is very simple, and suits admirably for engines fitted with a crank shaft and fly wheel.

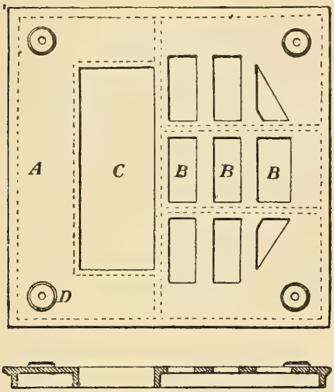


Fig. 159.—Bottom of Blowing Cylinder.
A, Bottom. B B, Valve openings. C, Discharge passage.

The *cylinder for the air* consists of a round barrel with flanges at the ends, truly bored out and the flanges faced; it is bolted down on a square base, which has nine openings for admitting the air into the cylinder, and one large opening for its exit. The former openings are fitted with flap valves, made of an elastic material, and backed with suitable wrought-iron plates; while the non-return valves for the bottom are fitted on the passages for taking away the air under pressure. The base is securely bolted down with one large bolt at each corner, passing through holes left in the foundation to the girder plates at the bottom, and the bolts are secured with keys bearing on these plates; thus the foundation is firmly bound together with plates at the top and bottom similar to the steam-cylinder end.

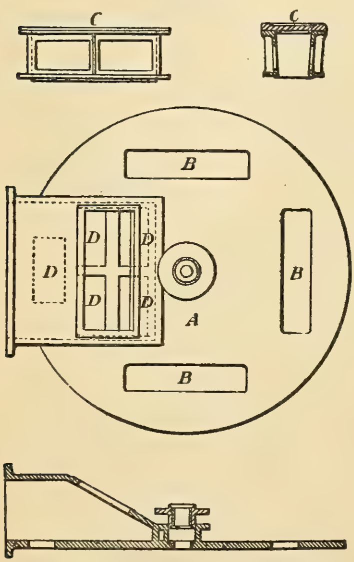


Fig. 160.—Cover and Valve Boxes for Blowing Cylinder.
A, Cover. B B, Valve openings. C, Valve chest. D D, Discharge valve openings.

The *cover* for the cylinder is fitted with a packing box and gland for the piston rod, and has three openings for the admission of the air, and five smaller openings placed inside of the branch cast on the cover for the exit of the air. The former are fitted with valve boxes, which are bolted down on the cover, and have a door fitted to the top of each box. There are four openings

in each, and the valves are arranged nearly in a vertical position, hinging from the top; while the valves for the exit of the air are

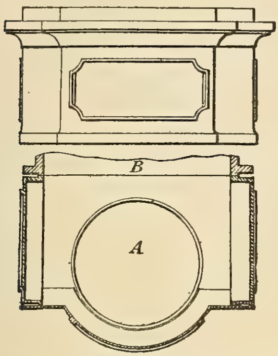


Fig. 161.—Top Chest for Blowing Cylinder.
A, Top chest. B, Passage on the cylinder cover.

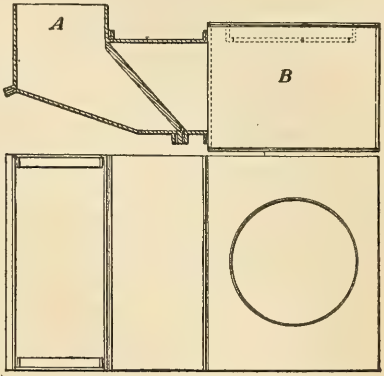


Fig. 162.—Bottom Chest for Blowing Cylinder.
A, Passage for cylinder. B, Bottom chest.

placed quite flat on the cover, and are secured—as all these valves are—with bolts and nuts, having a narrow strip of plate for the nuts to bear on at the hinge.

The *top and bottom chests* for taking away the air are formed of separate plates bolted together like a tank, and the joints rusted with a cement made of fine cast-iron borings, sal ammoniac, and sulphur. The proportions used for this cement are—sal ammoniac, 2 parts; flower of sulphur, 1 part; cast-iron borings, 200 parts. It requires some time to set, and makes a first-rate joint. The top chest is bolted to the flange cast on the branch, and the bottom one is let into the socket cast on the base plate and then rusted up, and is fitted with an inclined plate between the socket and the bottom discharge chest—this plate having four openings for the non-return valves. The top and bottom chests are connected by means of a circular column, securely bolted at the top and properly jointed, no expansion joint being required. The pipe for leading the air to the wrought-iron receiver is fitted to the bottom chest, the line of piping being circular.

Fig. 163.—Distance Pipe for Air Chests for Blowing Cylinder.
A, Distance pipe. B, Loose ring.

The *piston* for the blowing cylinder should be light, yet strong. It is fitted with a narrow junk ring for pressing down the packing, and held down with bolts and nuts let into the piston. The piston rod has a cone fitting into a corresponding cone in the piston, and is secured with a plain cotter passing through the boss of the piston and rod.

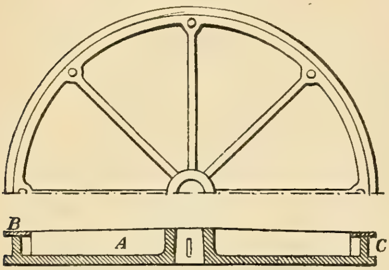


Fig. 164.—Piston for Blowing Cylinder.
A, Piston. B, Junk ring. C, Packing space.

We will now consider the details for actuating the pistons of the steam and air cylinders simultaneously. The *main beam* is cast in two halves, and held together by cast-iron distance pieces with flanges for bolting to the halves. All the holes for the main gudgeons should be accurately bored out, and the gudgeons turned to fit. The one for the main connecting rod has collars turned on it, and should be placed in position before the beams are bolted

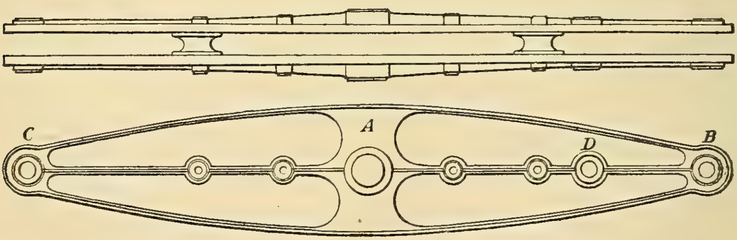


Fig. 165.—Main Beam.
A, Beam. B, Steam cylinder end. C, Air cylinder end. D, Boss for connecting-rod gudgeon.

together; all the other gudgeons, excepting those for the feed and cold water pump, have the journals on the outside of the beam, and can be put in at any time; they are held in position with keys. Some engineers prefer fitting four keys on the main gudgeons, the hole being left larger, and after the keys are fitted lead is run in, filling up the space; but this does not make such good work as boring out the hole the exact size. For heavy cast-iron beams of all descriptions, neat wrought-iron hoops should be shrunk on the main boss, thereby binding the part that takes the whole strain that is transmitted through the beam.

The *pillow blocks* are of the usual description, fitted with brasses,

which are secured by means of covers and bolts; a broad base is cast on the pillow block, and bolted at the ends to the spring beam,

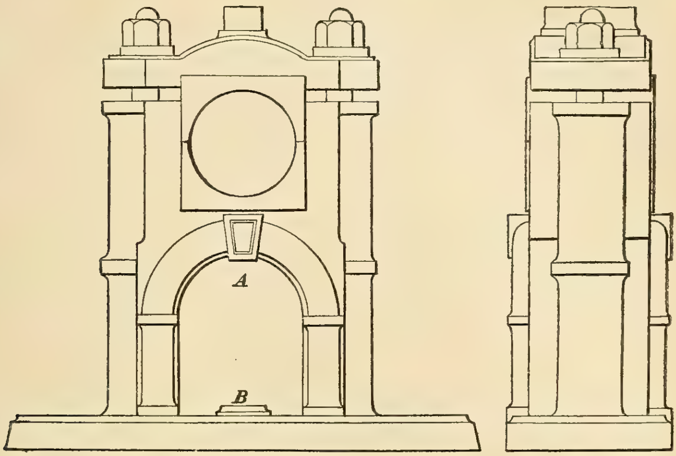


Fig. 166.—Pillow Block for the Gudgeon of the Main Beam.

A, Pillow block. B, Boss for holding-down bolt.

while the large central bolt passing down through each column also passes through a hole in the spring beam and base of the pillow blocks, the nut bearing on the top of the base plate—thus firmly bolting the pillow blocks, spring beam, entablature, and columns together.

The *spring beam* is a light frame of cast iron running the entire length of the engine house, and is built into the walls at the end. The part inclosing the beam is formed as a half circle at the ends, and in long spring beams a cross beam runs across the engine house at each end, and is built into the side walls. The spring beam proper ends at this cross beam, but its continuity is maintained by bolting girders to the ends, which are built into the walls; these and the cross girders are placed in mainly to support the spring beam and carry the floor. In some cases stone flags are laid down, but open cast-iron foot plates are preferable, and when neatly executed give a light and airy appearance to the engine room. When the engine is under repair, heavy weights must not of course be placed on such a floor. Planking should be laid down on the top of the beams which run across the engine room for carrying the cast-iron floor plates; they should be made with thin raised parts,

with side flange pieces. By this means the floor plates are supported, and kept slightly apart from one another in the length of

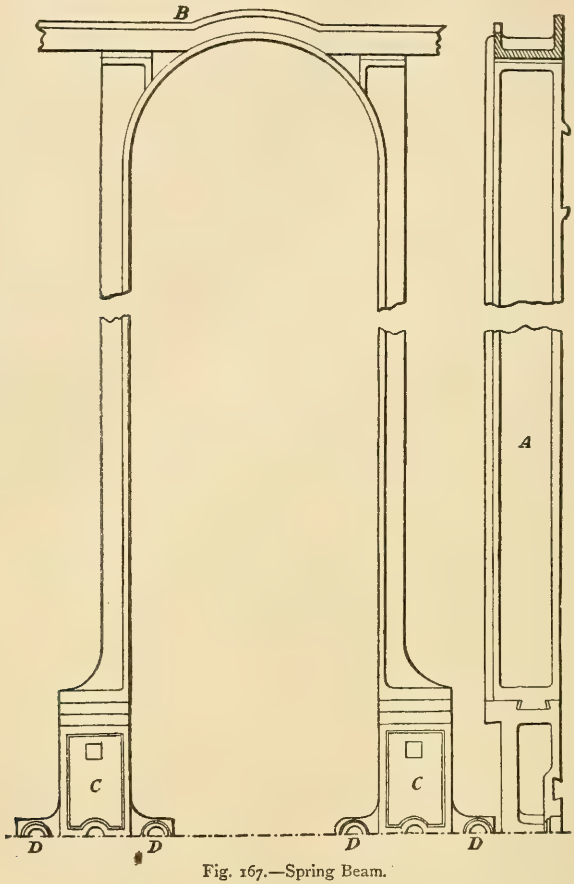


Fig. 167.—Spring Beam.

A, Spring beam. B, Cross beam. C C, Pillow-block seats. D D, Bosses for holding-down bolts.

the building, but across the building they are simply placed end to end.

The *entablature* placed between the spring beam and the top of the columns runs across the building, and is built into the side walls, and securely joggled and bolted to the spring beam. It is best to form the entablature in two pieces, which are placed a short distance apart, and are hollowed out to take a projection cast on the top of each column. All these longitudinal and cross beams are supported by two columns, which rest on cast-iron plates laid on

the top of the foundation; each column is bolted down with one central bolt passing down to the bottom of the foundations, and a cross plate takes both of the bolts, which are secured at the ends

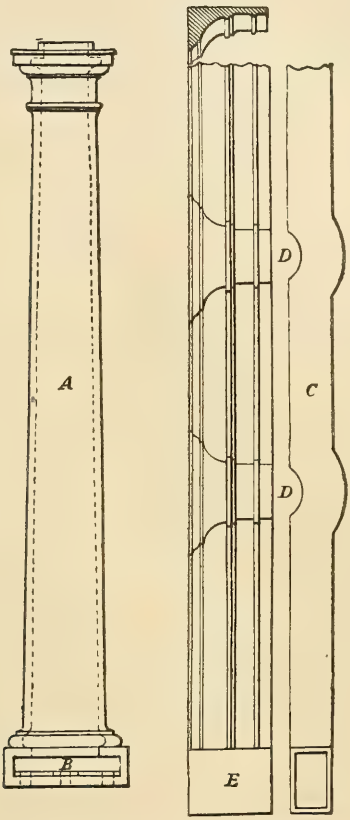


Fig. 168.—Pillars and Entablature.

A, Pillar. B, Recess for bolt heads. C, Entablature. D D, Hollows for pillars. E, Wall box.

with proper keys, like all the main holding-down bolts for the cylinders and crank-shaft arrangements.

The *pillow blocks for the crank shaft* are fitted with thick brasses and strong caps and bolts, and at the crank end a plate is laid down, butting against the steam cylinder and central pedestals of the foundation. This plate has fitting strips cast on it with the necessary joggles for fitting and securing the blocks at the ends; holes are also cast in it for bolting the pillow block to, and for the

holding-down bolts which pass down through the foundation. At

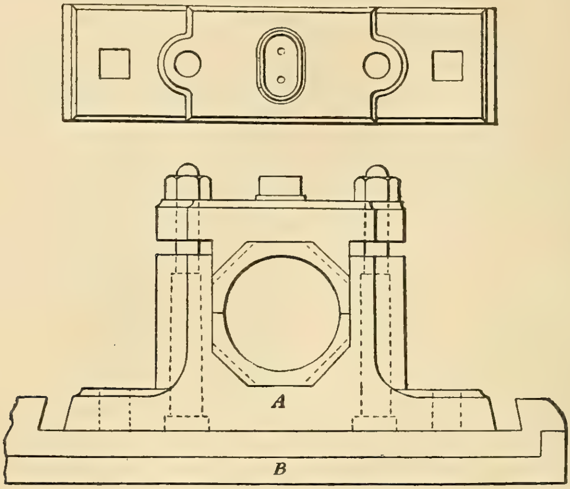


Fig. 169.—Pillow Block for Crank Shaft.
A, Pillow block. B, Bed plate.

the other end of the crank shaft a plate is let into the side wall, a proper arch being formed in the wall for its reception.

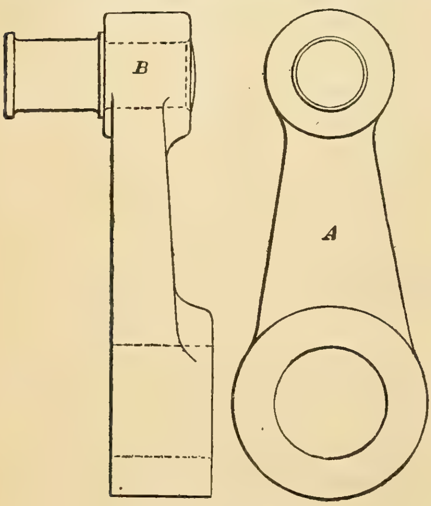


Fig. 170.—Main Crank.
A, Crank. B, Crank pin rivetted in.

The *crank shaft* and *crank* are of wrought iron, the latter being bored in the main eye, somewhat smaller than the part of the shaft where it is shrunk on. The crank is slightly heated for that purpose, it is then slipped on the shaft, and cold water poured over it, thus shrinking it tightly on. The shaft should be only a very little more in diameter than the eye, as when too much is allowed it is apt to strain the material and weaken the eye. The crank and shaft should have a keyway cut prior to the operation of shrinking on, and when it is cleaned out quite smooth

and fair the key is driven tightly in with a few strokes of a sledge hammer, and then cut off and filed quite smooth at the ends. The crank pin is held firmly in its eye by heating the eye and driving the pin in with a hand hammer, and then pouring water over it, the eye contracting and firmly binding the pin, which is then rivetted over at the end, a part being turned out in the pin for that purpose.

The *main connecting rod* is generally of wrought iron. turned from end to end, except the square parts for taking the straps, which are fitted with brasses, having a jib and key, with a screw turned on the key, which passes through an oblong hole in the bent part formed on the jib, the screw being fitted with a nut on each side of the jib. The rod is finished bright all over, or at least it should be turned all over and painted. Some connecting rods for the

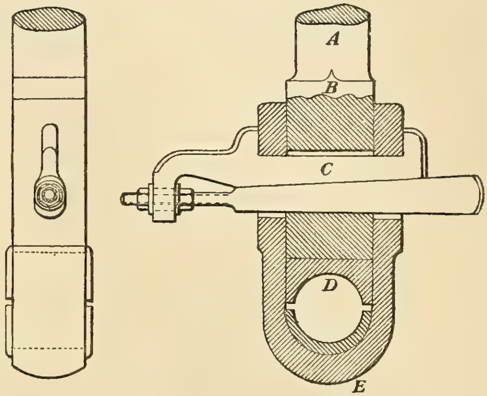


Fig. 171.—Connecting Rod.
A, Body of rod. B, Butt. C, Jib and cotter. D, Brasses. E, Strap.

blowing engine are made of oak, with wrought-iron straps on each side, well bolted and hooped, and a metal piece at each end securely bolted through the straps; this piece is for the brasses to abut against. The latter are held in position with jibs and keys. Although this form of connecting rod has not such a handsome appearance as the metal one, yet it answers the purpose very well. There is but little strain on it, as it merely (in connection with the crank) changes the reciprocating motion of the pistons,—in fact, it should just be made stiff enough to resist the strain at the dead centre, as it is termed, elsewhere it merely imparts motion to the fly-wheel shaft. It must be borne in mind, however, that a wrought-iron connecting rod balances the heavy piston of the air cylinder much better than one made of lighter material.

For convenience of transportation the *fly wheel* is built up in segments. Its central part is cast in one piece, and suited for eight arms, each arm having its segment cast along with it. These segments are dovetailed into one another at the joinings, and then

firmly secured with oak and thin iron wedges; the same mode of fastening the arms into the central part being adopted. Of course

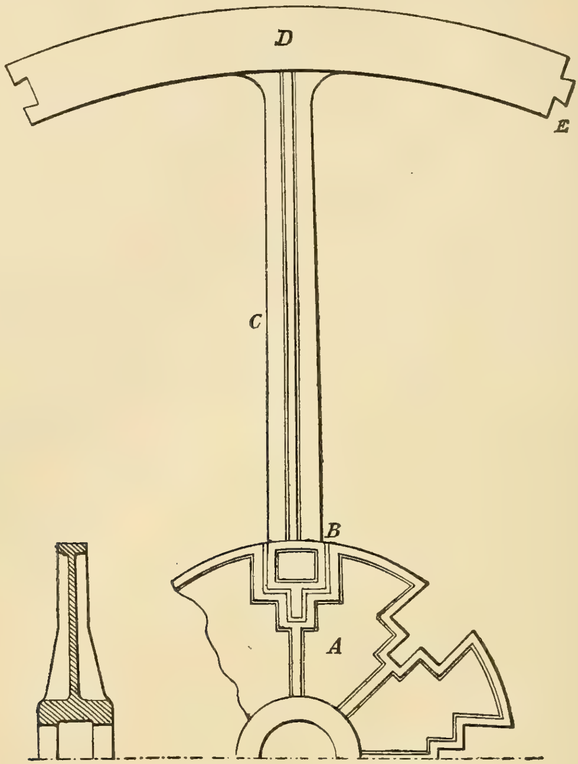


Fig. 172.—Fly Wheel.

A, Boss. B, Wedging space for arm. C, Arm. D, Rim. E, Dovetail at end.

there are other ways of fastening with bolts and nuts, used for fly wheels for general purposes. The boss is keyed on the shaft with a number of keys; but it is preferable to bore out the eye the same diameter at the raised part of the shaft, where it is fitted on with four keys, and a wrought-iron hoop should be shrunk on each side of the boss; by this means the keys can be firmly driven home without danger of splitting the boss, although there is not much risk of this when the metal is properly proportioned and care is taken to fit the keys; they should in the first instance be driven with a hand hammer until nearly home, with the surface bearing all over and filed quite smooth, then a few blows with a large hammer are given to complete the operation.

The piston rods of both cylinders are connected to the beam by

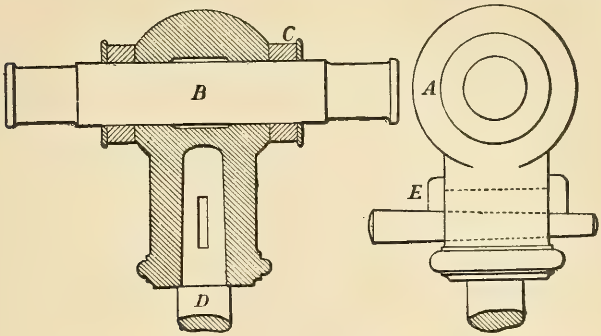


Fig. 173.—Crosshead.

A, Cast-iron crosshead. B, Gudgeon. C, Collars. D, Piston rod. E, Jib and cotter.

cast-iron *crossheads* and wrought-iron side links, and the vertical

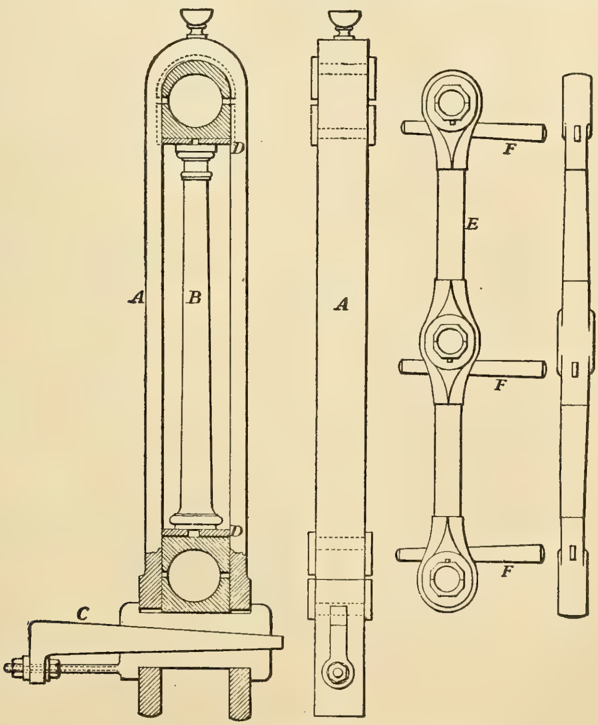


Fig. 174.—Main and Back Links for Parallel Motion.

A, Main link. B, Distance pillar. C, Jibs and cotter. D D, Plates. E, Back link. F, Cotter for brasses.

line is attained with the ordinary parallel motion, having fore and back links, parallel bars, radius rods, and cross gudgeons for the back links. The cast-iron crossheads are turned all over, and are secured to the piston rods with jibs and cotters; on each side a cast-iron ring and thin brass collar is laid on the gudgeon, which is secured with a key at each end; the outside bearings are for the main links, while the large eye of the parallel bar is placed between the main links and the brass washers.

The *main links* (Fig. 174) are plain wrought-iron straps, fitted with brasses at the top and bottom, having a distance column between them, bearing on wrought-iron plates fitted between the flanges of the brasses at the bottom of the top pair and at the top of the bottom pair; these brasses are held in position with two jibs and one key, a screw bolt being formed on the bottom jib, fitted with two nuts, one on each side of the eye formed on the end of the key, an elongated hole being made in the eye. The straps in some cases are turned all over on the outside, and oil cups formed on their tops; when got

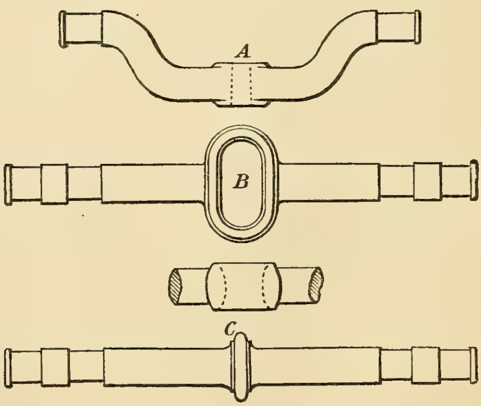


Fig. 175.—Bull's Eye and Cross Shafts for Parallel Motion.
A, Cross shaft for cold-water pump rod. B, Bull's eye for cold-water pump rod. C, Cross shaft.

up in first-class style they add greatly to the beauty of the engine. The back links are two plain round rods; the one for the steam cylinder has eyes forged on the ends, fitted with brasses held by a single key, and the one for the air-cylinder end has an eye at the middle for taking a bent cross bar, to which the cold-water pump rod is secured. The bottom bar has an elongated eye at the middle for the rod to pass through, the cross bar for the back link of the

steam-cylinder end being quite plain. The parallel bars are fitted to the crosshead and to the cross bars on the back links, the brasses being adjusted with a single key; the radius rods are similar, and work on a pin fitted to a bracket which is secured to the spring beam at the cylinder end, and the other eye takes the cross bar for the back links. In setting out this parallel motion, the length of the links from centre to centre is one-half of the piston stroke; the centre for the back links on the beam is equidistant from the end of the beam and the centre of vibration. The parallel and radius rods are exactly this length from centre to centre, or the distance from the back-link centre to the end centre of the beam; the true line of the piston rods being one-half of the versed sine of the chord contained by the full arc delineated by the travel of the beam, taking the distance from the end centre to the centre of vibration as the radius.

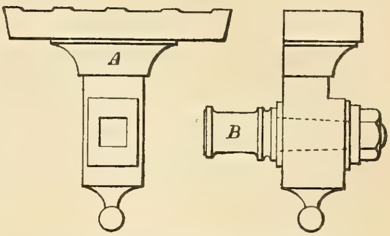


Fig. 176.—Bracket for Parallel Motion. A, Bracket. B, Pin secured with nut.

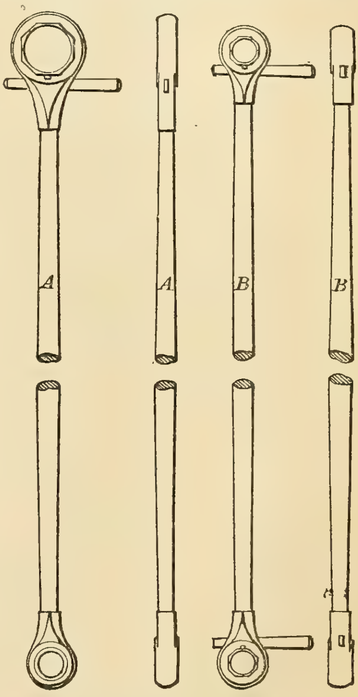


Fig. 177.—Parallel and Radius Rods for Parallel Motion. — A, Parallel rod. B, Radius rod.

The *cold-water pump* is a plain open barrel, fitted with a suction valve of leather, stiffened with wrought-iron plates at the top and bottom, rivetted through and through, and hinged on a separate conical valve seat. A cross bar, having an eye at the top, is fitted for holding down the leather, and for drawing out the valve and seating; this is secured to the latter by a cotter passing through the shank forged on the cross bar, the cotter bearing on the under side of the web cast along with the seating. The bucket is fitted with a valve of a similar descrip-

tion. The packing of the bucket is a plaited gasket, or gutta-percha rings may be adopted, and kept to the circumferential surface of the barrel by the hydraulic pressure of the water, a small hole being bored at the top in communication with the recesses left in the bucket. The pump rod is connected to the cross shaft placed at the centre length of the back link, passing through an eye formed on the shaft at the bottom end. The water is pumped into a cistern provided with an overflow pipe, the exhaust steam passing over the surface of the water and then escaping through another pipe into the atmosphere; by this means the feed water is heated before it is forced into the boiler by a plunger pump, the rod for working it being connected directly to the beam by a gudgeon passing through it, and to the plunger with a pin joint. The valves and their seatings are of brass; and a relief valve should be fitted, loaded with a weight, to return the water into the well or pond from which it is drawn by the cold-water pump. This of course is only required when a regulating valve is placed on the boiler; but should the valve for regulating the supply to the feed pump be placed on the suction pipe, a relief valve may be dispensed with. In either case, however, it is desirable to have one fitted close to the pump, so that in the event of the water in the feed pipes freezing the line of piping may not be damaged; and to guard against this evil, a small plug tap should be fitted to the line of feed pipes, and so placed that all the water may be run off between the check valve on the boiler and the pump.

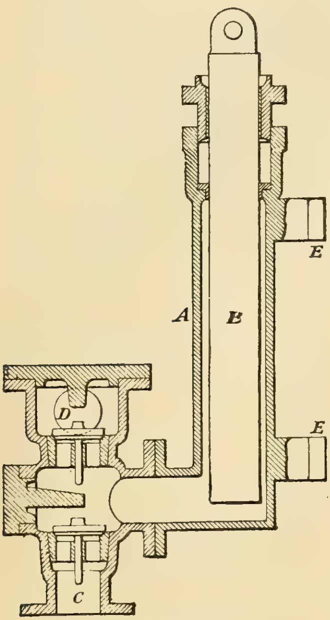


Fig. 178.—Feed Pump.
A, Pump. B, Plunger. C, Suction valve. D, Delivery valve. E E, Brackets.

The *steam-regulating valve* fitted to the nozzle chest should be placed so that the attendant can reach it easily when starting the engine. It consists of a sluice valve of brass, fitted on a cast-iron face, accurately planed and scraped to a true surface,—the valve chest being fitted with two covers to facilitate the operation of

scraping truly. One of these covers is fitted with a packing gland for the valve rod, which is actuated with a lever handle having a stud fitted to the valve box, with a joint and pin for taking the starting handle. The valve rod is secured to the valve with a pin passing through two snugs cast on the valve, and has a slot crosshead keyed on the outside, which the handle passes through.

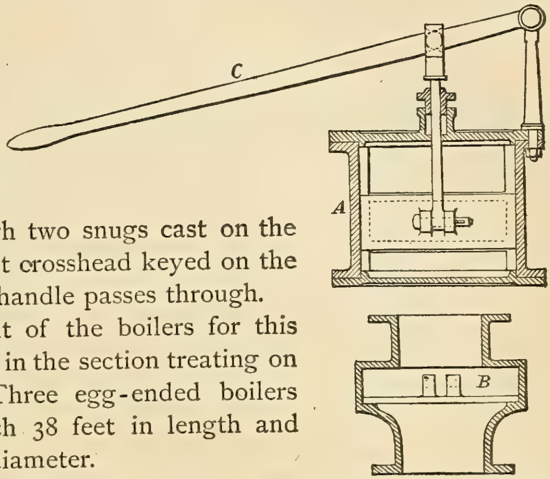


Fig. 179.—Steam-regulating Valve. A, Valve chest. B, Valve. C, Handle.

The arrangement of the boilers for this engine is described in the section treating on boilers (p. 39). Three egg-ended boilers were supplied, each 38 feet in length and 5 feet 7 inches in diameter.

In some examples of blowing engines erected at the Dowlais Iron Works the general arrangements are the same as the foregoing. The beam is supported on a wall carried up from the foundation, with a cast-iron wall box on which the pillow blocks are fitted. This pedestal is secured by long bolts and nuts passing through a plate at the bottom of the foundation; these bolts, passing from the top to the bottom, firmly bind together the lever wall. The pillow blocks are securely bolted and joggled to the wall box, and are fitted with brasses, but there are no caps, the brasses being held down with jibs and cotters passing through the sides of the pillow-block frame. Wooden spring beams are substituted instead of cast iron; they are let into the box on the lever wall, and pass along to the end walls of the engine house; transverse beams also are secured to the longitudinal ones for supporting the flooring. The beam is fitted with parallel motion, the main links taking the crosshead of the piston rods being placed between the beams, as are also the back links. The parallel bars and radius rods are fitted outside of these, the latter taking a pin on a cast-iron bracket bolted to the spring beam.

The *steam cylinder* in this example (Figs. 180, 181) is 55 inches diameter, stroke of piston 13 ft.; number of strokes per minute, 20; steam pressure, 60 lbs. per square inch. An ordinary slide valve

worked by an eccentric is fitted, having a gridiron expansion valve, working on the back of the valve casing, arranged to cut off the steam

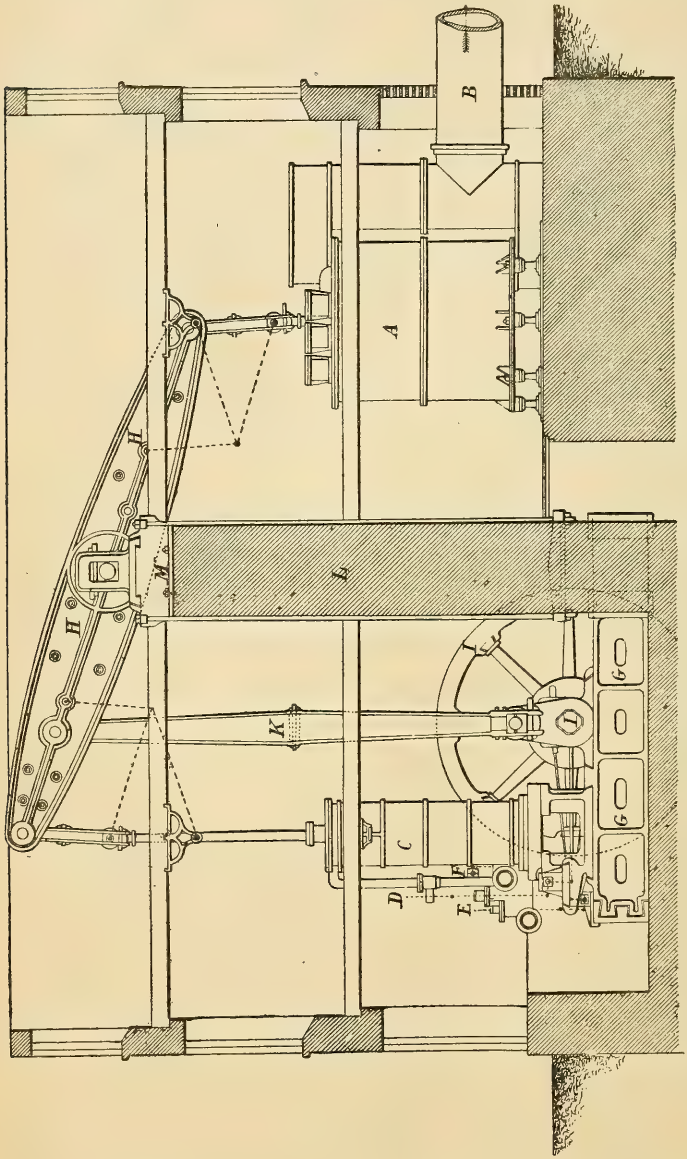


Fig. 180.—Blowing Engine at the Dowlais Iron Works. Side Elevation.

A, Blowing cylinder. B, Discharge pipe. C, Steam cylinder. D, Slide valve. E, Expansion valve. F, Small slide valve for moving the engine. G, Cast-iron framing. H, Main beam. I, Crank shaft. K, Connecting rod. L, Wall for supporting the beam. M, Pedestal.

at one-third of the stroke of the piston. Both of the valve chests are formed in one casting, each having a separate cover; they are

placed at the bottom of the cylinder, with a connecting pipe fitted with an expansion joint, forming the passage to the top of the cylinder. A separate slide valve is also fitted for starting the engine, which is

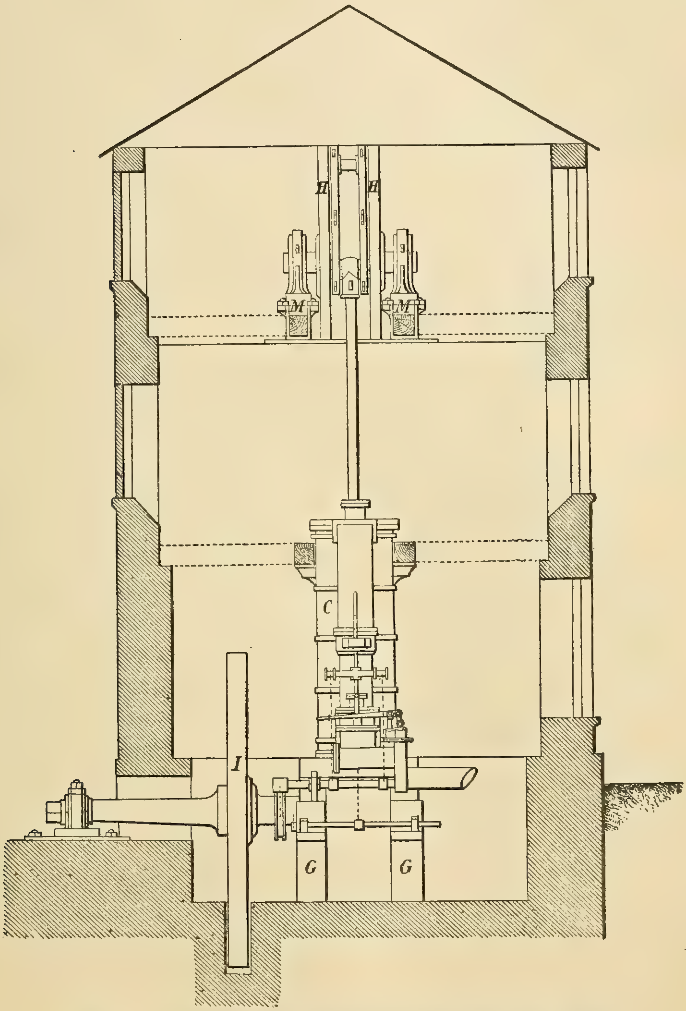


Fig. 181.—Blowing Engine at the Dowlais Iron Works. End Elevation.

worked by hand; but the main slide valve has the ordinary eccentric motion, with weigh shaft side rods and crosshead overhead, the valve rod being guided at the top by a stud placed on the passage between the top and bottom of the cylinder. The valve rod passes

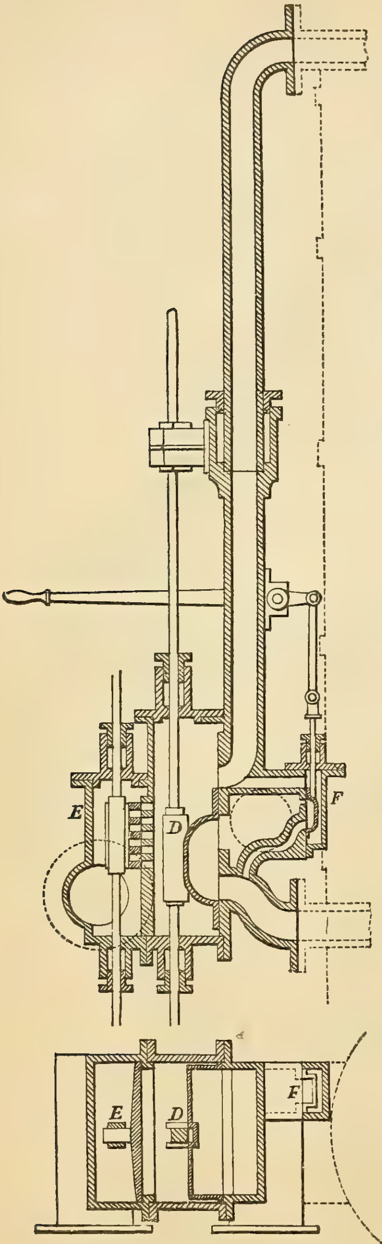


Fig. 182.—Section through Steam Valves.

D, Slide valve. E, Expansion valve. F, Small valve for moving the engine.

through a stuffing box on the under side of the valve casing. The expansion valve rod also passes through stuffing boxes at the top and bottom, and may be actuated by an eccentric or cam motion. The pedestal for bolting the cylinder to rests on massive frames of cast iron, and is raised somewhat above the line of the crank shaft; the castings under the cylinder weigh 75 tons, and the foundations contain 10,000 cubic feet of limestone in large blocks; thus securing a firm bedding for the machinery. When the main parts of such heavy castings can be run from smelting furnaces where the engine is to be fitted up, of course cast iron is largely used; but where transport is necessary recourse must be had to the usual mode of building the foundations with stone or brickwork laid in cement.

The *crank* is of cast iron, but the shaft is better of wrought iron, although many cast-iron ones are in use. The pillow block for the crank end rests on one of the frames to which the cylinder pedestal is bolted; the other end of the shaft passes through the side of the engine house, and is supported by a pillow block resting on a massive wall plate.

The *fly wheel* is 22 feet in diameter, weighs about 35 tons, and is fitted up in segments in the usual manner, the arms being fitted into

a large centre piece, and securely dovetailed into the rim at the extreme diameter.

The main part of the *connecting rod* is of oak, strapped with wrought iron from end to end, well bolted together, and in addition secured with a strong hoop shrunk on at the middle. Blocks of cast iron are fitted to the ends of the rod for the brasses to bear against, the blocks being bolted through and through the straps; and as both ends of the rod are forked, the brasses are adjusted with deep jibs and keys. The top end is placed between the beam, as in the previous example.

The *beam* has a total length of 40 feet between the outside centres, and is so arranged as to give a stroke of 13 feet to the steam piston and 12 feet to the air piston. It is cast in halves, each half weighing 16½ tons, the total weight on the centre gudgeon, including all the minor details, being about 44 tons. The wall for supporting the beam and its adjuncts is 7 feet in thickness, built of stone accurately dressed; the pedestal on which the main pillow blocks rest is bolted down with twelve bolts, 3 inches in diameter, taking a wall plate, the extreme breadth of the lever wall, placed below the level of the floor, for the blowing-cylinder end.

The *blowing cylinder* is 144 inches in diameter, stroke 12 feet; and as the piston makes twenty double strokes per minute, the quantity of air discharged is nearly 54,283 cubic feet per minute, delivered at a pressure of 3¼ lbs. per square inch. The area of the entrance valves is 56 square feet, and that of the delivery valves 16 square feet. The cylinder is cast in two pieces, and is bolted down to the bottom plate, which is strongly ribbed in the casting, and arranged with a suitable number of openings for the air flap valves. This bottom plate is supported on pillars of cast iron at convenient distances all round, which are stepped on a massive cast-iron plate resting on the top of the foundation, and to which it is bolted with long bolts passing down through the foundations, and secured at the bottom with keys bearing on a wall plate built into the stone-work. The cover is fitted with valve boxes, as in the previous example, the flap valves beating against the angular sides of the boxes. The boxes are fitted with covers at the top, through which the inside of the cylinder may be inspected. There are also fitted at the top and bottom large entrance valves, placed vertically immediately over and under the discharge passages. The non-return or discharge valves are placed in a line with and immediately

opposite the large entrance valves, and are fitted to the discharge chambers. The discharge pipe is 5 feet in diameter, it is carried 140 yards in length, and acts as a capital regulator, providing a

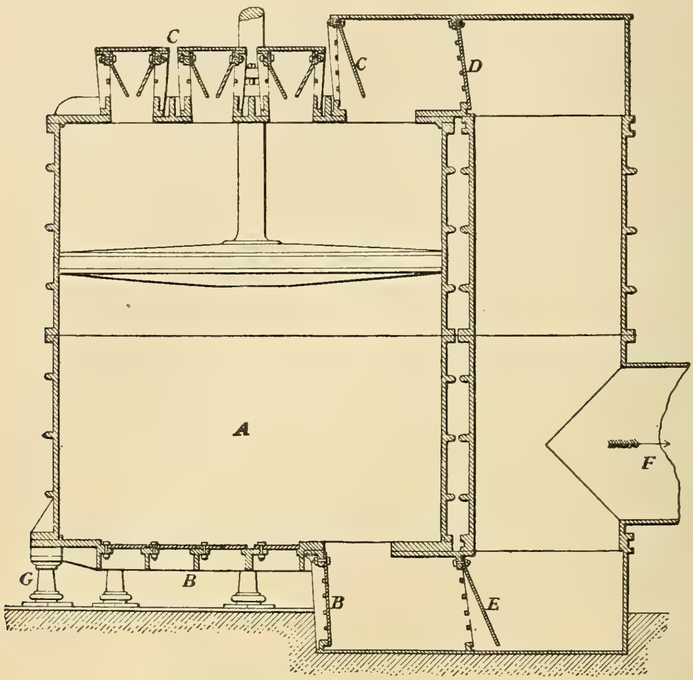


Fig. 183.—Vertical Section of Blowing Cylinder.

A, Cylinder. B B, Bottom valves. C C, Top valves. D, Top discharge valves. E, Bottom discharge valves. F, Discharge pipe. G, Pillars for supporting the bottom plate of the cylinder.

uniform blast to the furnaces, the engine being calculated for supplying a blast to eight furnaces, whose diameters across the boshes vary from 16 to 18 feet.

Eight *boilers* are supplied, of the Cornish description, each 42 feet long and 7 feet in diameter, with a single flue, 4 feet in diameter, running from end to end. The length of fire grate is 9 feet—which is too long to manage properly.

SIDE-LEVER COMBINED BLOWING ENGINES.

High and low pressure combined engines have been successfully adopted for blowing furnaces. The side levers, two in number, are placed one on each side of the steam cylinders; the high-pressure

cylinder being at one end, and the low-pressure cylinder at the other end. The blowing cylinders are placed overhead, and rest on stone pedestals built up from the foundation. The engine house

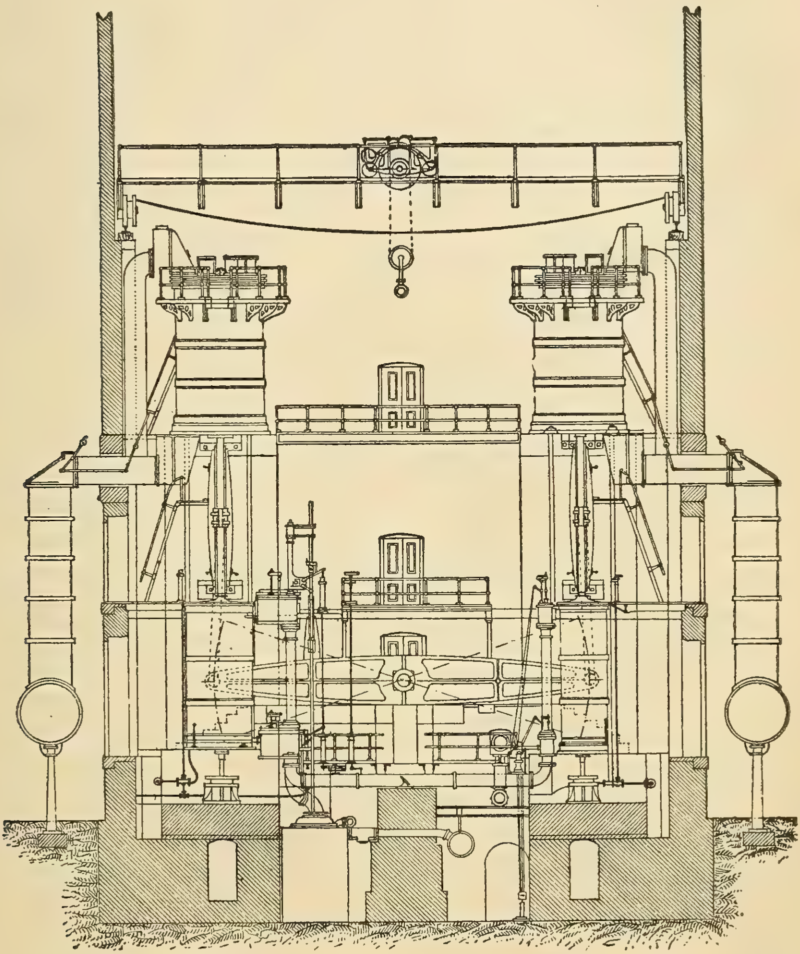


Fig. 184.—Side-lever Combined Blowing Engines, by Wilson of Patricroft.

is about 75 feet long, 60 feet wide, and 72 feet in height, and contains three pairs of engines.

The high-pressure cylinder is 45 inches, and the low-pressure one 66 inches in diameter; the blowing cylinders are each 100 inches in diameter; and the length of stroke for all the pistons is 12 feet.

Cornish valve gear, arranged for double action, is fitted to both of the steam cylinders. The steam, after doing duty on the top of the high-pressure piston, expands on the top of the low-pressure piston (and *vice versâ*), and then exhausts into the condenser; it will therefore be understood that two steam valves and two exhaust valves are fitted to each cylinder. The hand gear is placed on the low-pressure cylinder, and is connected by rods running below the flooring to the gear for the high-pressure cylinder; the attendant, therefore, from one platform can actuate by hand all the eight valves; or, in other words, the movement of the one set of gear for the steam valves of the one cylinder controls the movement of the steam valves of the other cylinder—the exhaust valves acting in the same way. Thus it will be seen that, with a steam and exhaust valve fitted at the top and bottom of each cylinder, the action will be as follows: Supposing steam from the boiler is acting on the bottom of the high-pressure cylinder, forcing up the piston, the lower exhaust valve and top steam valve are shut and the top exhaust valve open, while the top steam valve on the low-pressure cylinder is open and the top exhaust shut; thus the steam expands from the top of the small cylinder into the large one, at the same time the exhaust valve for the under side of the low-pressure cylinder is open to the condenser, the bottom steam valve being shut. The reverse of this takes place on the downward motion of the high-pressure piston. Thus the high-pressure piston is raised and depressed by steam direct from the boiler, while the low-pressure piston is raised and depressed by the exhaust steam from the high-pressure cylinder. An additional benefit accrues from the final condensation of the steam, as the top and bottom of the cylinder are in alternate communication with the condenser; power is thus gained and fuel economized. The arrangement of the Cornish valve gear may appear complicated when applied to one engine; but it must be remembered that this complexity consists merely in an increase of parts, as the whole of the gearing is joined together and works in unison.

The main side levers have a length of about 38 feet from centre to centre, and each weighs upwards of 20 tons; they are connected to the crosshead of the piston rod, common to both cylinders, by side rods. The vertical motion of the piston rods and crosshead is maintained by cast-iron guides, the distance from the top of the steam cylinders to the bottom of the blowing cylinders being about 17 feet.

The air pump is worked by means of a crosshead with connecting rods from the side levers; the plug rod for the valve mechanism is a continuation of the air pump rod, guided at the top with a bracket fitted to the nozzle chest. It is essential for this class of engine to have a travelling crane fitted overhead, so as to lift the pistons, &c., for inspection or repair.

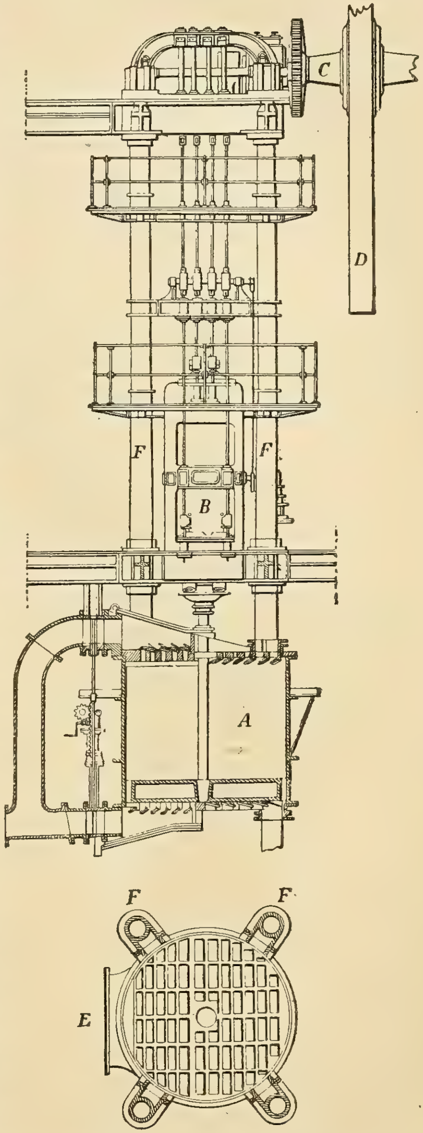


Fig. 185.—Vertical Blowing Engine at the Creuzot Iron Works, dep. Saône-et-Loire, France.
A, Blowing cylinder. B, Steam cylinder. C, Crank shaft. D, Fly wheel. E, Bottom of air cylinder. F F, Pillars.

VERTICAL BLOWING ENGINES.

Another example is the vertical direct-acting high-pressure engine, which differs materially from the foregoing in having no side levers or beams. The blowing cylinders are placed on the ground floor, four strong cast-iron pillars are securely fitted, one at each corner, and carried up to the top of the house, with cross girders for carrying the steam cylinder and fly-wheel shaft. The blowing cylinder is 108¼ inches in diameter, and the steam cylinder, placed overhead, is 47¼ inches in diameter; the stroke of each is 6 feet 6¾ inches. The fly-wheel shaft is 25 feet 10 inches above the floor of the engine, and the total height from the base to the centre of the crank shaft is about 44 feet 3 inches. The crank is connected by a rod to a crosshead working in guides,

taking the rod for the steam piston, which passes down through a stuffing box at the bottom of the steam cylinder, and is connected to the piston for the blowing cylinder. This class of blowing engine has a fly wheel; the valve gearing is worked from the fly wheel shaft, spur wheels being used to drive a cam shaft which actuates equilibrium valves. The steam is admitted into the cylinder at a pressure of 60 lbs. per square inch, and is cut off at

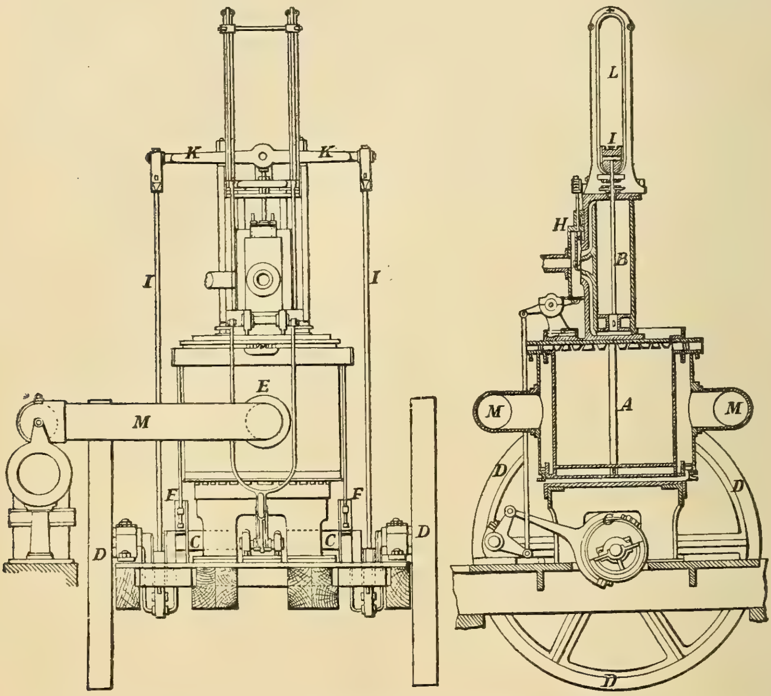


Fig. 186.—Table Blowing Engine.

A, Blowing cylinder. B, Steam cylinder. C, Crank shaft. D D, Fly wheels. E, Air valve. F F, Eccentrics for air valve. G, Eccentric for steam valve. H, Steam valve. I I, Side rods. K, Crosshead. L, Guides. M M, Air pipes.

about one-fourth of the stroke; the number of revolutions of the crank shaft is about fifteen. The inlet and exit valves for the blowing cylinder are arranged on the cover and bottom of the cylinder; small flap valves are used, one-half of the area being for the inlet, and the other half for the exit of the air, which is delivered at a pressure of about 3 lbs. per square inch, and the quantity is about 90 per cent. of the cubical contents of the cylinder at each stroke.

Vertical Table Engine.—We shall now notice the kind of blowing engines called "self-contained," that is, those erected on one bed plate carrying the whole of the engine. Of this class are the *vertical table engines*, which are constructed for easy transport, all the parts being as light as possible (Fig. 186). The blowing cylinder stands on a pedestal bolted to the bed plate. The diameter of the cylinder is 30 inches; stroke of piston 2 feet 6 inches, making 80 strokes per minute. These engines being small, a greater number of them must of course be provided; and when large sizes are adopted the weight of the various parts becomes a serious matter. The piston of the blowing cylinder is packed with hemp, with a junk ring to press it down. The openings for admitting the air into the cylinder are formed on the circumference at the top and bottom; a projecting flange is cast on at the top and bottom, the bars between the opening being inclined, similar to the piston-valve arrangement already described. The valve is of the annular description, encircling the whole cylinder from top to bottom; the rubbing surfaces are formed of brass rings accurately bored out. The body of the valve is formed of thin wrought-iron plates, securely fastened with a number of small bolts to two cast-iron rings, which are bored out inside for the reception of the brass packing rings. These rings fit the recesses in the cast iron and face on the cylinder without any other packing; and as they are cut through the wear can be adjusted with a thin slip of metal or paper, and then properly secured with bolts, although there is but little wear with this description of valve, owing to its being perfectly balanced. The air from both ends of the cylinder passes into the annular space between the cylinder and the valve, from which it escapes by two pipes, placed opposite each other, with flanges for jointing them to the cylindrical part of the valve. The pipes at the other end slide on a vertical surface prepared for them; the motion is small, as the pipes are long, and the vertical motion of the valve is not great. The valve is driven by two eccentrics, one on each side of the cylinder, with rods taking pins fitted to the top cast-iron ring. The steam cylinder is placed on the top of the blowing one, and is fitted with a common valve, with sufficient lap to cut off the steam at one-half of the stroke. The piston-rod crosshead is fitted with two connecting rods taking the cranked shaft, the crosshead working in suitable guides. Two

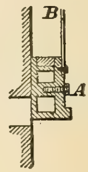


Fig. 187.[1]

[1] Section of Air Valve.—A, Valve. B, Plate for connecting valves.

fly wheels are fitted, thus less diameter is required for a given weight, and it is found desirable to limit the weight to 1 ton. When the means of transport is difficult no part of the engine should exceed this weight. These engines do not require massive and expensive foundations; they can rest on balks of timber with merely a few bolts to hold them down. They can also be driven at a high velocity, owing to the action of the valve preventing all blow and jar in the working, when the lap and lead are properly adjusted: a pair of them can be worked together, the cranks being at right angles to each other, causing great uniformity in the flow of the blast, and no regulator is required. A pair of these engines, with a piston speed of 400 feet per minute blowing 3600 cubic feet of air, make a very compact arrangement for small-power blowing engines.

HORIZONTAL BLOWING ENGINE.

Horizontal high-pressure blowing engines have been extensively used. In the following example (Fig. 188), which is one of the largest description, the diameter of the steam cylinder is 4 feet 3 inches, with a stroke of 9 feet. The blowing cylinder has a diameter of 108 inches, and the length of stroke is the same as for the piston of the steam cylinder, the number of strokes being about twenty-two, giving a total speed of 396 feet per minute.

The steam valves (Fig. 189) are of the piston type, which are very generally used for blowing engines, because they are perfectly balanced, and therefore suffer little wear and tear, which is a great desideratum with engines requiring to go day and night for a lengthened period. The valves are cast together with a pipe connection, each piston is packed with a single ring, which is kept up to the working face by a spring; the junk rings are each secured with a single nut having a thread cut on the valve spindle, which is central with the valves. The valve casing is a circular casting; the steam is admitted between the valves, and the exhaust takes place at both ends. The valves are arranged so as to make the steam ports as short as possible; and there is an annular ring round the piston, to give free entrance and exit for the steam all round the circumference of the valves. The valve rod passes through stuffing boxes at both ends of the casing, and as the valves are placed at the side of the steam cylinder, the motion for working them is direct, a plain

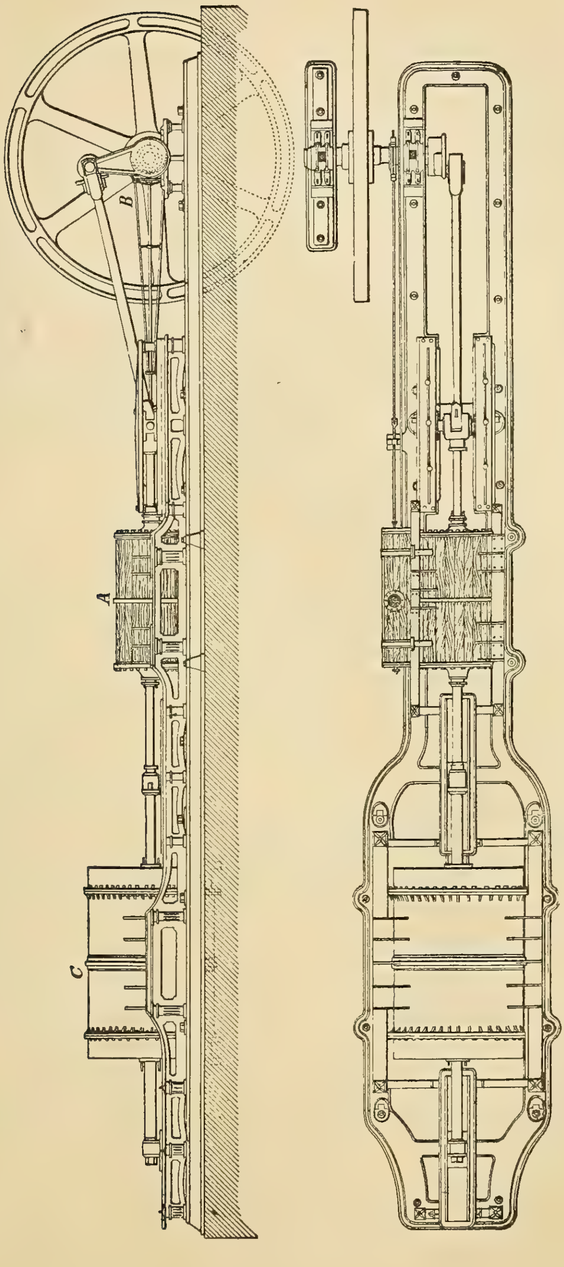


Fig. 188.—Horizontal Blowing Engine. A, Steam cylinder. B, Crank shaft. C, Blowing cylinder.

eccentric and rod being adopted, having a joint placed close up to the guide block for the valve rod, carried up considerably

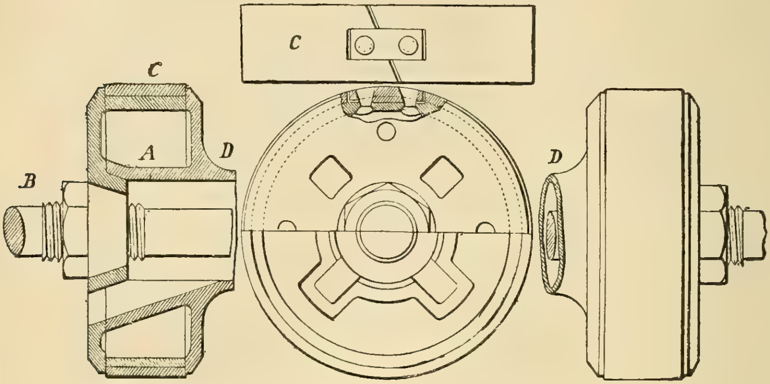


Fig. 189.—Steam Valve for Horizontal Blowing Engine.

A, Valve. B, Valve rod. C, Packing ring. D, Connecting pipe.

beyond the stuffing box, thus lessening the length of the eccentric rod.

The steam cylinder (Fig. 190) is of the ordinary description, with projections cast on for bolting down to the bed plate. It is provided with a cover and stuffing box at each end, through which the piston rod passes, with recesses for the nut and collar that secures the piston to the rod. The piston should be as light as practicable, and its ends strengthened with ribs in the casting; the packing is metallic, held up to the face with a number of short flat springs; the junk ring is bolted down with bolts and nuts recessed in the piston in the usual manner. To prevent radiation the cylinder and valve casing are covered with felt and wood lagging; and straps of wrought iron or brass are used to bind securely the wooden strips placed over the felt. The main crank is of cast iron, and is connected to the piston rod by a wrought-iron rod, with straps, jibs, and keys at both ends, having a wrought-iron crosshead and gudgeon with blocks working in cast-iron motion bars; thus one end of the piston rod is truly guided, while at the back end it takes a crosshead working into a slipper guide, to which the piston rod for the blowing cylinder is securely cottered.

The blowing cylinder (Fig. 191) is a plain casting, with side flanges for bolting it to the bed plate which runs the entire length of the

engine. The piston rod passes through both ends of the cylinder, and is guided with crossheads and slipper guides, as already ex-

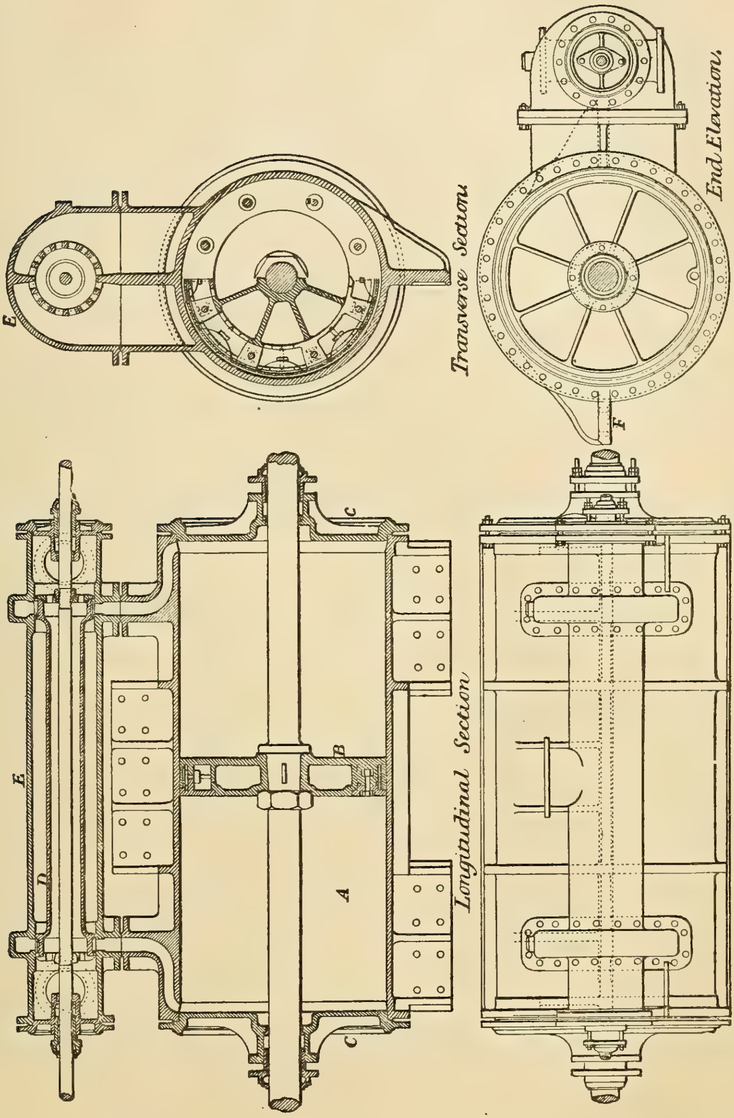


Fig. 190.—Steam Cylinder.

A, Cylinder. B, Piston. C C, Covers. D, Valve. E, Valve chest. F, Brackets for bolting down to frame.

plained. The diameter of the piston rod is greater than that for the steam cylinder, which tends to carry up the piston. Some

engines of this class have a trunk passing through both ends in a similar manner, by which means more bearing surface is obtained for carrying up the piston, it being supported as it were with a tubular beam,—thus reducing the wear and tear in the cylinder. The air valves are arranged in the covers, and consist of round discs, working on suitable gratings, with guards to limit the lift. The valves for the entrance of the air are placed centrally round the stuffing box for the piston rod, that part of the cover being strongly ribbed in the casting; and an annular chamber is cast round the circumference of the cover, which is fitted with valves of the same description for the exit of the air,—a large opening being left at the bottom, in connection with the main pipes, &c., to the furnaces. Small covers are fitted for the convenience of inspecting the exit valves.

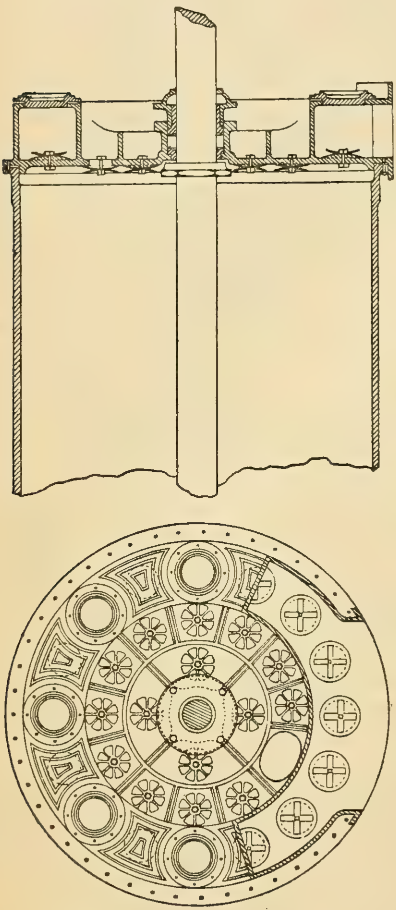


Fig. 191.—Blowing Cylinder and Cover.

This engine is used to blow air to two furnaces; the area of the blowing piston is 63·072 square feet, and it discharges 24,976 cubic feet per minute. As ample rubbing surface in all the working parts has been well considered, this engine has been found to be very economical in the matter of repairs. The diameter of the fly wheel is about 21 feet; and as the whole of the machinery is built up on one frame, from end to end, the foundation is laid in brickwork, with about 2 feet of stonework on the top. This class of engine is certainly the cheapest that can be supplied for heavy work; and the engine house need not be so large as for the overhead-beam arrangements.

ROLLING-MILL ENGINES.

Engines for driving rolling mills, &c., should be made strong, as they require to run for weeks without stopping. The examples shown in Figs. 192 and 193, of engines erected at the Dowlais Iron Works, are unusually strong. Cast iron is largely used in their construction. They are of the high pressure kind, coupled at right angles to each other.

The steam cylinders are 45 inches in diameter, with a stroke of 10 feet, making 24 double strokes per minute. Each cylinder has a common slide valve of brass, worked by an eccentric on the main shaft. The expansion valves are of the gridiron sort, worked by a cam on the main shaft, the steam being cut off at about one-third of the stroke; an arrangement is made for throwing these valves out of gear when the engines are doing heavy work. Each engine is fitted with a small slide valve to be worked by hand, for the purpose of starting and reversing.

The framing under the engines and machinery is of cast iron, and consists of four lines, each 75 feet long, 12 feet high, and 21 inches wide, the whole weighing about 850 tons. The whole engines are thus self-contained,—a very important point in this class of engine.

Each beam is in two parts, each part weighing about 17 tons, making the total weight of the beam when complete about 37 tons. The two beams are supported upon eight columns, 24 feet long and 2½ feet in diameter, securely fastened at the bottom in deep jaws cast upon the framing. Upon the top of each group of four columns is a large and heavy entablature plate, which carries the pillow blocks for the main gudgeons. Each column passes through the entablature, the bosses at the junction being 24 inches deep; these are bored out, and the tops of the columns turned, so as to insure a perfect fit. The pillow-block brasses are secured and tightened up by wrought-iron keys in the jaws of the pillow blocks, which are bolted down on the entablature, and further secured with joggles and keys.

The connecting rods are of oak, with wrought-iron straps; an experience of forty years having proved that such rods are the best, and more easily kept in repair than cast-iron ones, which are

liable to break, while wrought-iron rods are much heavier. The

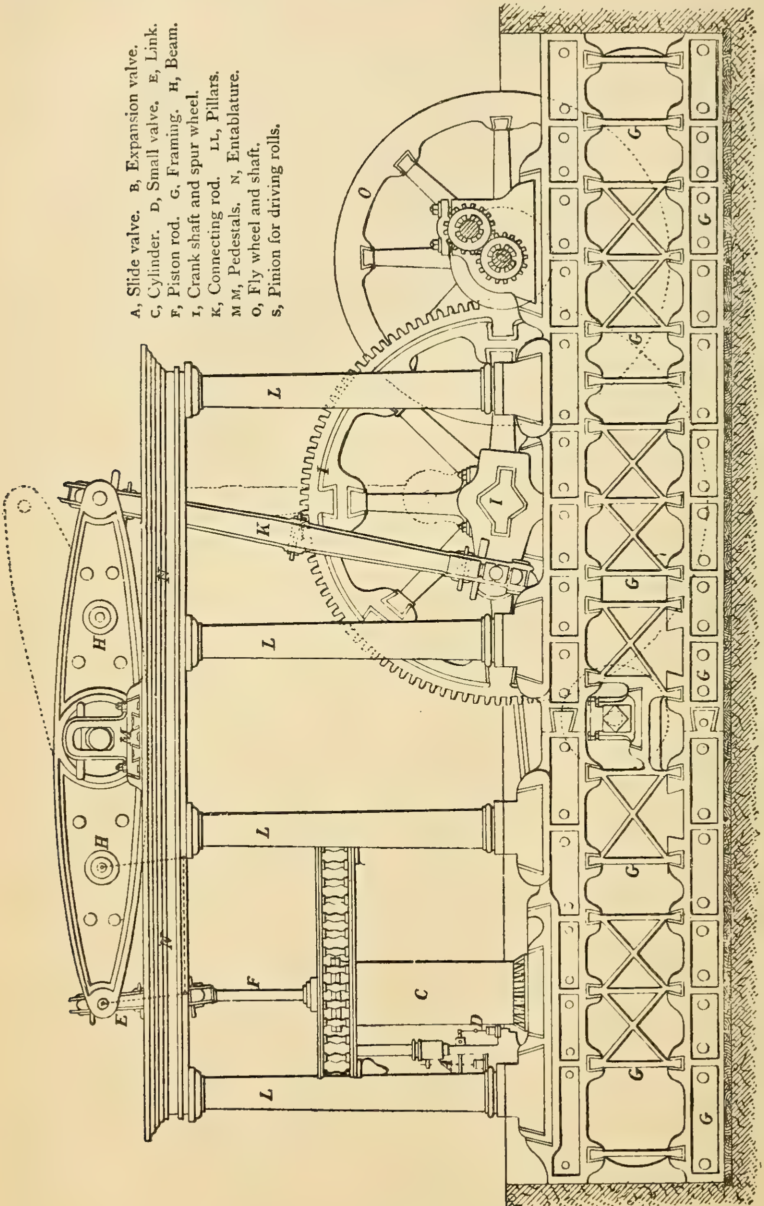


Fig. 192.—Rolling-mill Engine at the Dowlais Iron Works. Side Elevation.

oak rod, strapped with wrought iron, is better calculated to stand

the severe and sudden strain, as the material possesses an elasticity which tends to lessen the shock.

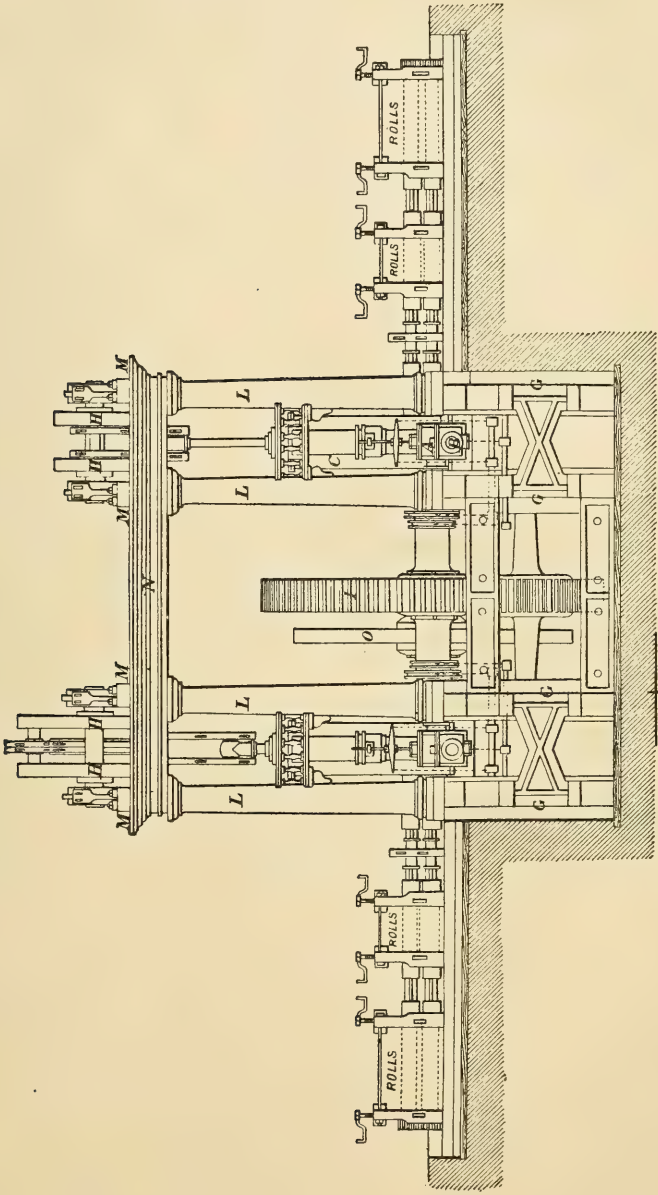


Fig. 193.—Rolling-mill Engine at the Dowlais Iron Works. End Elevation.

The driving-wheel shaft is of cast-iron, 24 inches in diameter;

the fly-wheel shaft is also of cast iron, with bearings 21 inches in diameter. The diameter of the driving wheel is 25 feet at the pitch line; the pitch is 7 inches, and the width of the teeth 27 inches. The diameter of the spur wheel or pinion on the fly-wheel shaft is 6 feet, and the teeth are strengthened by a flange running up to their points on each side. The fly wheel on the mill shaft is 21 feet in diameter, and weighs about 30 tons; it makes upwards of 100 revolutions per minute. The whole of the fastenings both of the wheels and framing are of dry oak and iron wedges.

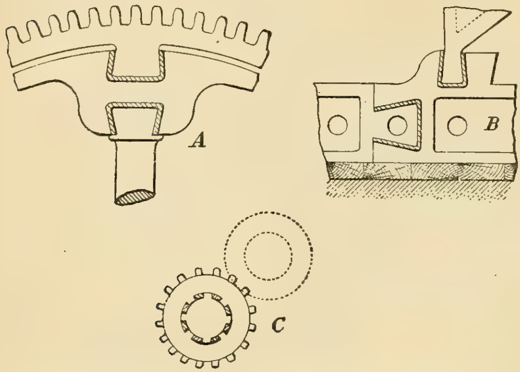


Fig. 194.—Details of Fly Wheel, Framing, and Pinions.
A, Fly wheel, showing mode of fastening. B, Frame, showing mode of fastening. C, Pinions.

The blowing engines of this firm, described in the preceding pages, are of 650 nominal horse-power, and weigh about 300 tons, including the bed plate; the pair of rolling-mill engines are of 1000 nominal horse-power, and contain about 1000 tons of metal, or 1 ton per nominal horse-power. This is very nearly double the ordinary proportion, but it is the practice of this firm to make their engines very strong, so as to avoid if possible the need of stoppages of the works caused by a break-down of the machinery. The steam for the rolling-mill engines is supplied by six Cornish boilers, each 44 feet long and 7 feet in diameter, with a 4-feet tube. The whole of the plates are best Staffordshire, $\frac{9}{16}$ inch thick; the total weight of the boilers is about 120 tons.

These engines can drive one rail mill capable of turning out 1000 tons of rails per week, another mill capable of making 700 tons of rails or roughed-down per week, and one bar or roughing-down mill, capable of making 200 tons per week; thus turning out a total of about 2000 tons of iron per week. Two blooming mills with three high-rolls and two hammers, are also worked by the same engines. The saws and small machinery are driven by separate engines, as also the punching and straightening machines. The roofs cover a space of 240 feet by 210 feet, and are formed of

corrugated black plates, No. 14 wire gauge in thickness. The spans are 50 feet, the roofs being supported upon lattice girders of an average length of 45 feet. The position of the columns is shown on the ground plan, Fig. 195; and it will be observed that the entire

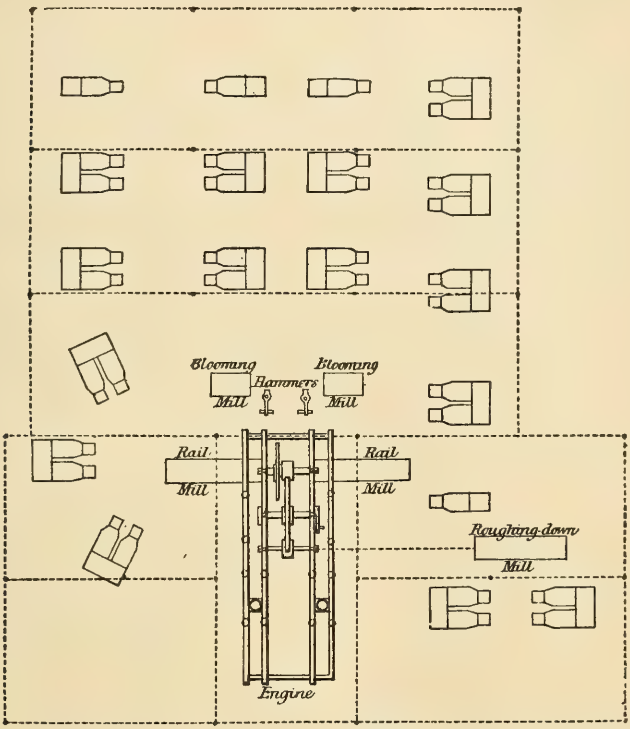


Fig. 195.—General Arrangement of Rolling Mill. Ground Plan.

mill floor is free from obstruction. The flooring is of cast-iron plates, 1 inch thick.

It had long been felt that the power of rolling wrought iron of large section and great lengths had not kept pace with the requirements of engineers, who were frequently hampered in their designs by the impossibility of obtaining iron of sufficient dimensions. For engineering works of any magnitude bars of great length, considerable width, and moderate thickness are often required; and in the ordinary mode of rolling, the length and width of the bar are measured by the power of the engine and the time occupied in rolling. It is obvious that to finish a bar quickly it is necessary

that it should be rolled in two directions to prevent delay; and long and heavy bars can be thus rolled only by an engine of enormous power, such as the large combined engines we have described.

A simple arrangement of rolls for working in two directions has been adopted, by which means large bars of thin section are finished

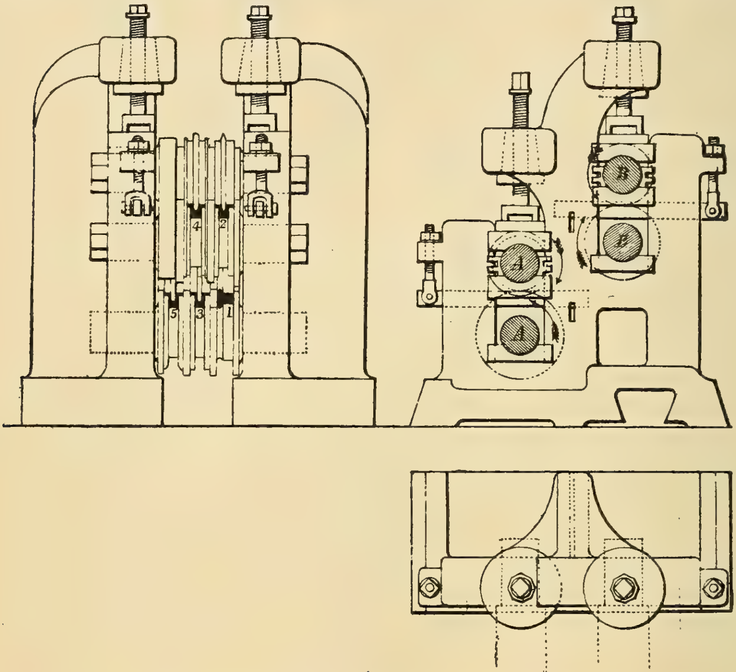
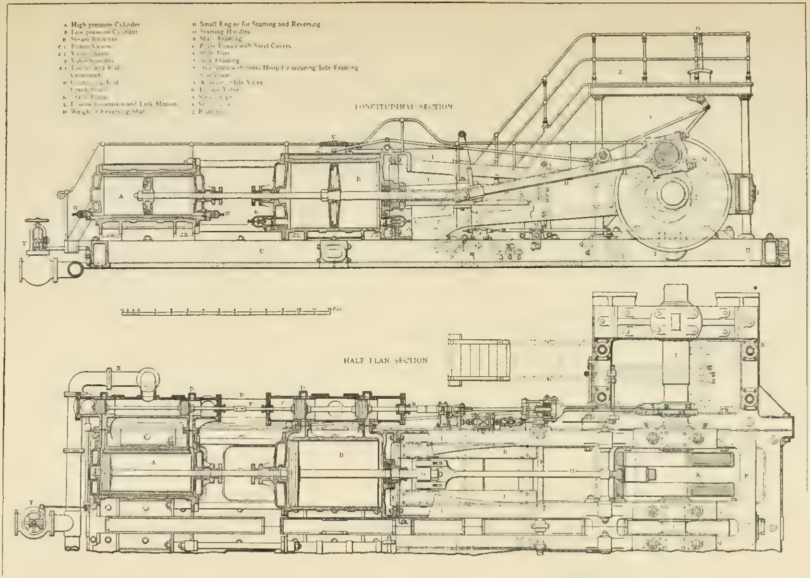


Fig. 196.—Arrangement of Rolls for rolling in two directions.

A A, Rolls driven from fly-wheel shaft. B B, Rolls driven from the fly-wheel shaft by a pair of wheels C C, Fig. 194.

in one heat, as it is impossible to get such large bars into the furnace to re-heat. In ordinary rolling so much time was lost in bringing back the bar over the top of the rolls that it was found impossible to make the larger sizes required for modern work, and the plan was therefore adopted of having a second pair of rolls running in the opposite direction, placed at the back of the first rolls, as seen in Fig. 196, the lower one of the second pair being raised just enough above the upper one of the first pair to clear the bar in coming through, and the bar is passed back through the second rolls, and then through the third, fourth, and fifth rolls as may be required, as shown by the figures in the engraving. By



COMPOUND REVERSING ROLLING MILL ENGINES, STEEL COMPANY OF SCOTLAND'S WORKS AT HALLSIDE, NEAR GLASGOW

CONSTRUCTED BY MESSRS. MILLER & CO., COATBRIDGE

this means much time is saved over the ordinary method, with the additional advantage of being able to manufacture bars up to 60 feet long, for deck beams and keels of iron ships, in one length without a weld, which can only be effected by having a high speed of the rolls so as to complete the work before the bar gets too cold. Reversing gear has been used for the rolls, but it is not to be recommended for them when running above forty-five revolutions per minute, on account of the violent shock in reversing the motion at a higher speed. To roll the length required for the above purposes the speed at the Dowlais Iron Works is nearly three times as great, the ordinary rolls running at 120 revolutions per minute, and the others for large sections at 110 revolutions, the rolls being of the full size—21 inches in diameter.

COMPOUND REVERSING RAIL MILL ENGINES,

AT HALLSIDE STEEL WORKS, NEAR GLASGOW. (SEE PLATE.)

"The engines are of the compound direct-acting horizontal type, and have two high- and two low-pressure cylinders, whose diameters are respectively 31 inches and 50 inches, while the length of stroke is 5 feet. They act directly on the rolls, by which arrangement there is obtained a very high speed in the rolling operation with a comparatively limited speed in the engines, the latter making from fifty and sixty revolutions per minute. In each case the high-pressure is placed in rear of the low-pressure cylinder, with which it is connected by means of an intervening receiver. Laid upon a bed of hard and tough blue clay, the foundation of these engines —the total weight of which is some 300 tons—consists of a solid mass of Portland cement concrete, 12 feet or 14 feet in thickness, and weighing between 500 tons and 600 tons. To this foundation is fixed the soleplate, which weighs about 60 tons, and carries the two pairs of cylinders, as also the two main frames. The latter, which are of the box form, are, as will be seen in the Plate, arranged so as to form a direct connection between the low-pressure cylinders and the crankshaft, while the pedestals for the crankshaft bearings are cast solid with them. Under each crankshaft bearing the frame has a strong foot, which is not only bolted down to the soleplate by two holding-down bolts, but which has in addition on

each side oval bosses, on which there are shrunk steel hoops for tying down the central part of the foot to the soleplate; while the ends are keyed in between strong snugs cast on the same plate. Each crankshaft bearing is provided with four brasses, one above and one below, and one on each side. The fore and aft parts are fitted with movable wedge blocks which take up the wear, these blocks being provided with slotted eyes, and being suspended by means of bolts, which are flat-headed, but of a circular form. The top brasses are adjusted with set screws, and both they and the bottom brasses are held in position by the top cover, which bridges over the opening in the frame. On each side of this opening there is a strong dovetailed projection over which the cover is placed. Itself a strong steel forging, this cover is most securely keyed in position, in addition to which it is bolted down hard and fast. The arrangements just noticed result in the most rigid connection being effected between the fore and aft portions of the engine framing. Between the crankshaft bearings and the guide bars the frames have cast on them horn-like brackets, through which pass stay bolts carrying suitable distance pieces, thereby securing at this part of the framing an amount of rigidity quite equal to that which

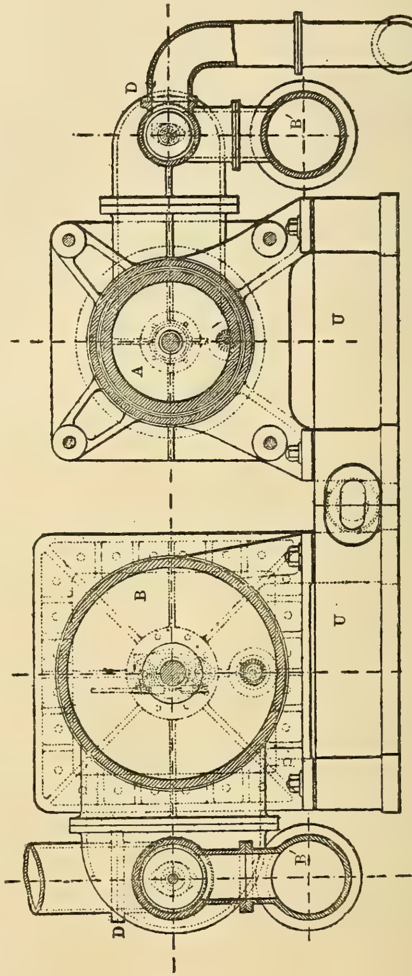


Fig. 196A.—Section through Cylinders.
A, High-pressure cylinder. B, Low-pressure cylinder. B′, Steam receiver. D, Valve chests. U, Sole plate.

exists in the anterior portion. Inside the main frames there are fixed the slide bars, which are adjustable, top and bottom, for the purpose of taking up the wear. The upper one is made plane throughout, but the lower one is of a trough shape. They are made of the best forged steel, as, indeed, are all the working parts of the engines.

The high-pressure cylinders are each fitted with a liner, the space between this and the cylinder casting proper forming a steam jacket; the low-pressure cylinders, however, are not jacketted. At their forward ends each of the low-pressure cylinders is solid, and is provided with a bracketted flange where it is in contact with the main frames; and connection between the frames and the cylinder ends is effected by means of bolts, no studs being used.

The valves of these engines are of the double-piston type. The steam ports in the valve casings have triangular openings into the valve cylinders, the valve pistons having a 9½ inch stroke, and being fitted with broad packing rings which are furnished with cylindrical springs of a V shape. A tight-working piston is thereby obtained, no escape of steam having been observed at any pressure yet employed. The object aimed at in employing this type of valve was to relieve the valve motion of the severe tear and wear resulting from the use of unbalanced flat-faced valves.

The valve casings are placed on the sides of the cylinders in order that they may be easily got at for inspection or in case of repairs being necessary. The receiver formerly mentioned as intervening between the high- and low-pressure cylinders of each engine is immediately underneath the valve casings, and serves to catch up any water that might otherwise enter the cylinders. The valve spindles are of steel, and are jointed together by means of a box coupling provided with cotters—an arrangement which allows of the pistons and spindles being easily withdrawn for repairs and replaced in position.

Steam is admitted into the high-pressure cylinder by the piston valve entering between the pistons of the valve, and exhausting at each end into the receiver. The distribution of the steam into the low-pressure cylinder is similarly effected by its valve, the steam entering at the middle of the valve, and exhausting at each end as before. On the top of the low-pressure valve casing there is placed a small auxiliary slide valve, which is worked from the link motion of the main valve, and is in direct communication with the steam

of full boiler pressure, so that in the event of the rolls failing at any time to 'bite' when the ingot or bar in process of rolling is about to enter, the driver can at once admit steam at full pressure direct from the boilers upon the pistons in the low-pressure cylinders, and turn it off instantaneously when the desired effect is accomplished. The valve just referred to consists of a D-slide working on the face of a grid plate having openings similar to the valve ports, and serving the purpose of a shut-off valve as well as a slide valve. The motion of this valve is governed by the general link motion of the engines, thereby insuring that there shall never be any uncertainty as to the admission of the steam pressure on the proper side of the piston. Both high- and low-pressure cylinders are provided at each end with spring escape valves.

The crankshaft, which weighs 10½ tons, is a fine steel forging, and extends from the coupling to the mill to the right-hand engine, or engine furthest from the mill.

The crankshaft bearings are 18 inches in diameter, as are also the crank-pins.

The several levers by which the operation of starting, reversing, &c., are controlled, are all within a few inches of each other, and there is nothing to intercept the driver's view of what is going on at the rolling mill, in front or in rear, or of the whole surface of the engines. The engines are started and reversed by the aid of a small steam cylinder provided with cataract regulation.

The engines we have been describing drive a 26-inch mill. They are worked with steam at 120 lbs. pressure, and are capable of easily developing 3000 horse-power.

The steam for driving the engines we have been describing is supplied by boilers of the locomotive type, these being three in number.

The boilers have barrels 6 feet 2½ inches in diameter, and each contains 336 tubes, 2½ inches in diameter by 12 feet long. The tube surface in each boiler is thus 2640 square feet, while the firebox surface is 171½ square feet and the firegrate area 30 square feet. The fireboxes are each provided with a longitudinal mid-feather; and in each case the roof of the inside firebox is stayed direct to the casing by steel stays. The two front rows of these stays are arranged with their upper ends in sockets, so as to allow for the expansion and contraction of the tubeplate of the firebox. Arrangements are made for a firebrick arch resting on angle-irons. No

brick setting is required for the boilers, which are, instead, set on cast-iron frames, which serve as stands on each side of the firebox and smokebox, in this way again giving allowance for freedom of motion during expansion and contraction. Each boiler is supplied with a couple of Cockburn's 2¼ inch diameter open-flow pendulum valves, each of which is loaded to a working pressure of 120 lbs. per square inch. Prior to delivery the boilers were experimentally subjected to a water pressure of 250 lbs. per square inch, while they were also tried under steam to the pressure just mentioned. They have already proved themselves to be excellent steam raisers. Practically the whole of the material of these boilers is steel; the principal exception being that of the tubes, which are of iron."[1]

THE CORLISS ENGINE.

An engine combining economy of working with a moderate first cost must ever be of primary importance. The distribution of steam effected by the ordinary slide valve actuated by the single eccentric has, after long trial, been found to yield unsatisfactory results; many ingenious improvements have been adopted, and amongst these is the "Corliss" liberating valve gear, named after the inventor.

The characteristic features which are common to all the forms of liberating valve gear may be thus briefly stated:—The steam is cut off almost instantaneously by the agency of some force suddenly called into play, such as a falling weight or the recoil of a distended spring, the cut-off being regulated to the amount of work the engine has to perform directly by the controlling agency of the governor and the cut-off gear. The Corliss engine has separate pairs of steam and exhaust valves, or altogether four for each cylinder. They are of the cylindrical type; the lower of them, or the exhaust valves, are wrought directly from the eccentric by means of a disc plate and levers connected with the valve spindles; they remain open during the whole period of the stroke, and are not affected by the cut-off gear. The steam valves are likewise wrought from the disc plate by levers, which open the valves at first, and so distend a steel spiral spring whilst the steam is being admitted, till on the

[1] For the description and plate we are indebted to *Engineering*, vol. xxvii.

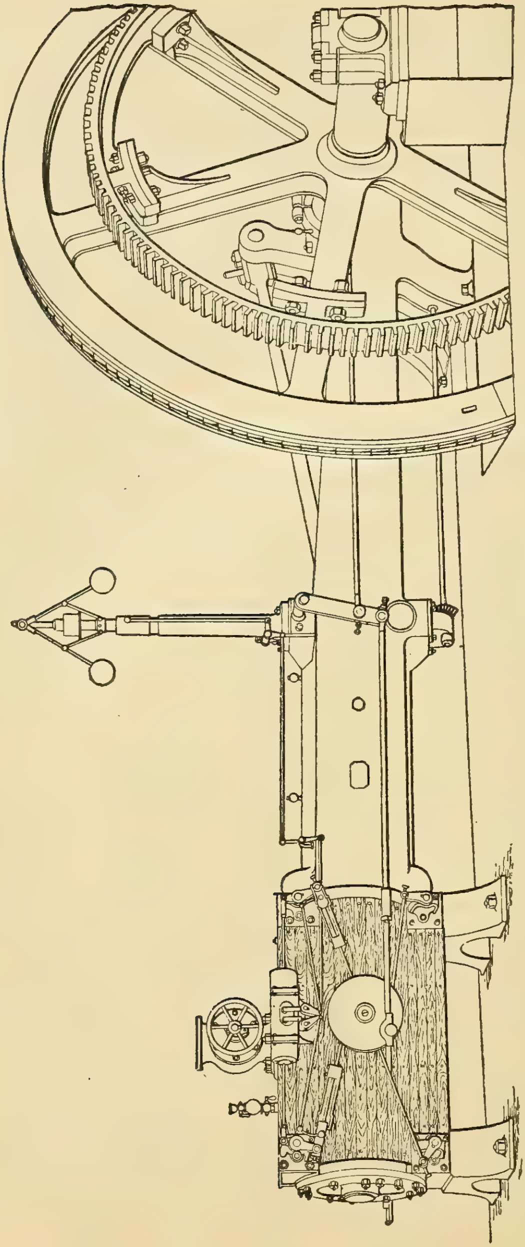
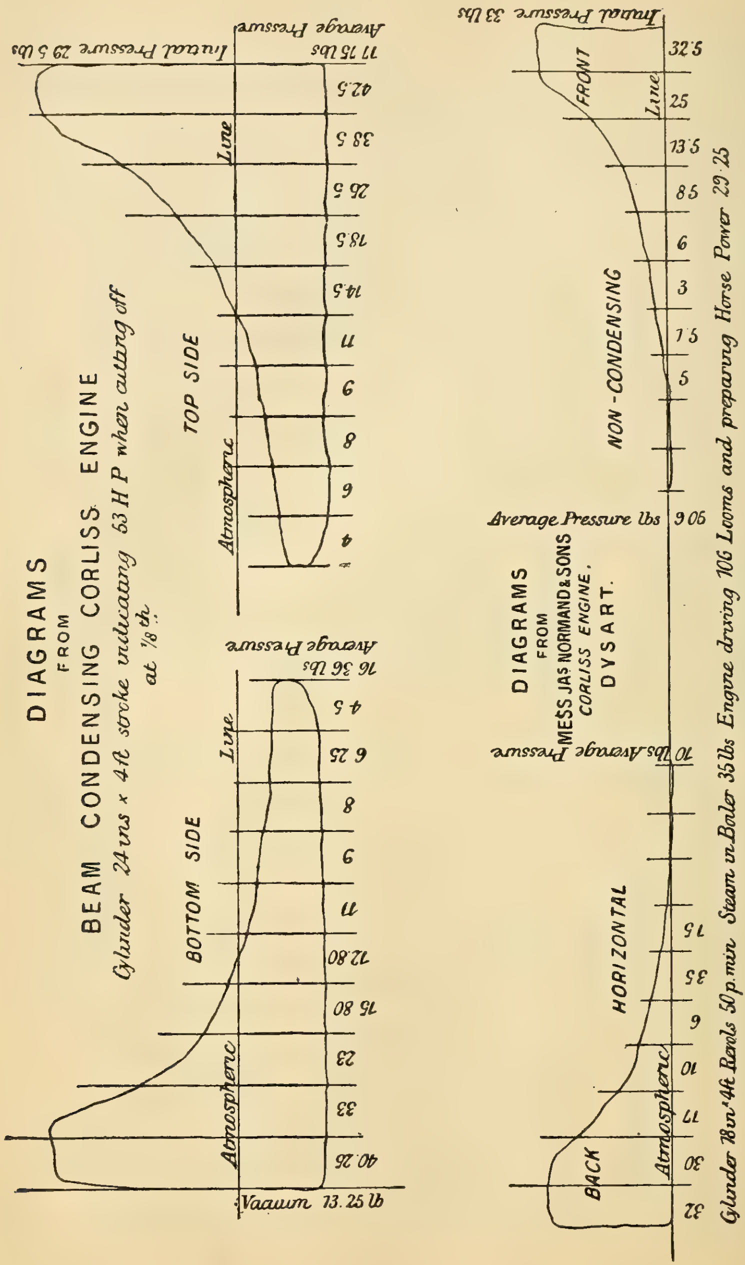


Fig. 197.—The Corliss Engine.

lever reaching a certain position it is tripped up by a peculiarly-

shaped toe-piece liberating the spring, which by its recoil instantly closes the valve. To guard against the damage that might possibly arise from the too violent impact of the spring, it is closed in a dash pot or vessel, to which the air is admitted by small holes, but prevented from escaping freely, and which forms a cushion to check the impact of the spring and bring it gradually to rest. The governor is connected with the cut-off gear by levers, by which the point where the lever is tripped may be altered as the cut-off requires to be hastened, or delayed according to the power required from the engine. No throttle valve is therefore employed to wire-draw the steam, and by a fall of pressure (involving a direct loss of energy) to vary the power given out by the engine; but the better expedient is adopted of supplying exactly the quantity of steam required to perform the work. With what efficiency this arrangement answers will be best gathered from the following instance:—In a spinning factory a cogged wheel was instantaneously stripped, the resistance portion of the work which it drove was thus suddenly removed; but so perfectly did the engine draw the reduced quantity of steam that on examination not a single thread was found to be broken. Pumping machinery also affords another instance, as not even the breaking of a spear rod sensibly affects the speed of the engine.

As has been already stated the Corliss engine has separate steam and exhaust valves. Not to mention the good results in the working of the engines which are due to this arrangement, the separate valves effect a direct economy, as each valve is kept at a constant temperature, and the steam that enters through them directly from the boiler is not cooled down as it would be if it entered through the same passage by which the exhaust steam had previously escaped, neither is the exhaust steam again re-heated by contact with the hot steam valve; we have thus a direct saving of heat, which in an ordinary slide-valve engine would be lost. The steam lost by clearance when performing work is with these valves reduced to a minimum. To test thoroughly the actual working of this engine the indicator must be summoned to our assistance; and the diagrams obtained from it will enable us to judge to what extent the theoretical diagrams, or those that give the maximum amount of power from a minimum consumption of steam, agree with those realized in practice. The conditions necessary to insure the maximum of efficiency may be thus briefly stated:—(1) The ports must



Figs. 198 and 199.

be fully open during the whole period for the admission of steam.

(2) The cut-off must be rapid. (3) The back pressure must be a minimum. (4) The steam must be admitted into the cylinder at its full boiler pressure until the point of cut-off is reached. In the Corliss diagrams these conditions are strictly fulfilled. The admission of steam is indicated by a nearly perpendicular line, Figs. 198 and 199, and the cut-off must, with the means employed, be practically instantaneous. The diagrams exhibit a remarkably small back pressure; this result, along with the constancy of pressure maintained until the point of cut-off is reached, is accounted for by the large area that can be given to the steam and exhaust passages, as the valves employed are of the whole breadth of the cylinder.

In ordinary engines a large expenditure of power is required to move the valves; this loss of power is saved in the Corliss engine, as one man with an ordinary starting bar can move the valves of a 1000 horse-power engine against the full pressure of steam. As every part of the engine is readily open to inspection, no difficulty is experienced in examination, and repair of any of the parts requiring it; but in practice the wear is found to be very slight. The Corliss engine is economical in the matter of fuel, its consumption being at the rate of 2½ lbs. per horse power per hour, as proved by experiment,—a result that must go far to recommend it to the favourable notice of manufacturers requiring steam-power.

HIGH AND LOW PRESSURE COMBINED BEAM ENGINE.

The high and low pressure combined beam engine is much used where great regularity of motion is required, more especially for driving spinning machinery. This regularity of motion is due to the steam expanding from the top of the high-pressure to the bottom of the low-pressure cylinders, and *vice versa,* by which the jerk at the commencement of the stroke of the piston is not so much felt as in ordinary engines receiving the full force of the steam on one side of the piston. The example illustrated, Fig. 200, consists of a pair of engines, coupled at right angles, for driving the machinery at the Royal Gun Factory at Woolwich. The diameter of the fly wheel is 22 feet at the pitch line, the breadth of the teeth 12 inches, and the pitch 3 inches, gearing into a pinion 4 feet 6 inches in diameter.

Speed of the engine shaft	21	revolutions per minute.
Do. second shaft	102	,, ,,
Do. third shaft	150	,, ,,

The total length of the shafting is about 932 feet, in parallel lengths, the diameter of the pinion shaft being 8 inches, and that of the

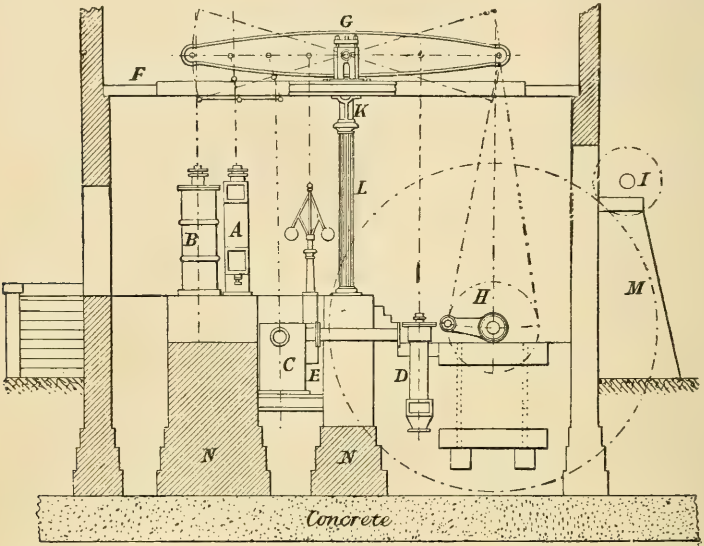


Fig. 200.—High and Low Pressure Combined Beam Engines of 80 horse-power collectively.

A, High-pressure cylinder. B, Low-pressure cylinder. C, Condenser and cistern. D, Cold-water pump. E, Governor and feed-pump rod. F, Spring beam. G, Main beam. H, Crank shaft. I, Pinion shaft. K, Entablature. L, Columns. M, Stone pedestal. N, Foundation.

smaller line of shafting 3 inches at the end. The diameter of each high-pressure cylinder is 15½ inches, stroke of piston 4 feet 6 inches; and the diameter of each low-pressure cylinder is 31 inches, with a piston stroke of 6 feet. The valve mechanism for those engines has already been described, p. 102, Fig. 51. The diameter of each air pump is 21 inches, with a stroke of bucket of 3 feet. The crank shaft is of cast iron, the journals being 10 inches in diameter and 15 inches long, and the crank pins 5½ inches in diameter and 7½ inches long. There are three large boilers, 35 feet long and 7 feet in diameter, with two inside furnaces, and flues running the entire length, 2 feet 6 inches in diameter, with return wheel flues of brickwork. The steam pressure is 40 lbs. per square inch, and the thickness of the plates is as follows:—

Shell	½ inch thick.	Flues	⅜ inch thick.
Ends	⅝ ,,	Rivets	¾ inch in diameter.

RULES FOR PUMPING ENGINES.

Horse-power.—The standard fixed upon to represent the work of one horse is 33,000 lbs. raised 1 foot high in one minute. To find the horse-power, the quantity of water to be raised is reduced to lbs. and multiplied by the height in feet, and the product divided by 33,000 expresses the horse-power. A gallon of water weighs exactly 10 lbs., thus any number of gallons can be expressed in lbs. by adding a cipher. Hence the following formula:

$$\frac{\text{Gallons to be raised per minute} \times 10 \times \text{height}}{33000} = \text{horse-power.}$$

But in practice about one-fifth must be added for the friction of the engine. Examples:—

Supposing 1000 gallons of water per minute is required to be pumped through a line of piping to a height of 120 feet, and the allowance made for the friction in the pipes is equivalent to a head of water of 150 feet: required the horse-power. Thus we have—

$$\frac{\overset{\text{Gals. per minute.}}{1000} \times \overset{\text{Lbs.}}{10} \times \overset{\text{Height in feet.}}{150}}{33000} = 45{\cdot}45$$

to which add $\frac{1}{5}$th for the friction of the engine = 9·09

54·54 horse-power.

Again, supposing 1,440,000 gallons of water is required to be pumped up in the 24 hours the same height, we have—

Gals. in 24 hours.		Lbs.		Height.		Lbs. raised 1 foot high per minute = H.P.		mins.		hours.		
1,440,000	×	10	×	150	÷	33000	×	(60	×	24)	=	45·45

adding as before $\frac{1}{5}$th for friction of the engine................ = 9·09

54·54 horse-power.

Another method gives the horse-power as follows:—

Gals. in 24 hours.		Height.		Constant.		
1,440,000	×	150	÷	4,752,000	=	45·45

$\frac{1}{5}$th added = 9.09

54·54 horse-power.

Supposing the quantity is given in cubic feet to be delivered in the 24 hours, at the same height as before, we have—

Cubic feet in 24 hours.		Weight of a cubic foot in lbs.		Height in feet.		Lbs. raised 1 foot high per minute = H.P.		mins.		hours.		
230,400	×	62·5	×	150	÷	33000	×	(60	×	24)	=	45·45
						$\frac{1}{5}$th added..................					=	9·09
												54·54 horse-power.

The power required to raise water to any height is as the weight and velocity of the water. Hence the following rule: Multiply the perpendicular height of the water in feet by the velocity in feet, by the square of the pump's diameter in inches, and then by ·341 (the weight of a column of fresh water 1 inch in diameter and 12 inches in height), dividing the product by 33,000; the quotient gives the horse-power, to which must be added one-fifth for friction, and say one-fifth for loss, or two-fifths in all. For water-works' engines 20 per cent. is allowed for friction, &c., and about 50 per cent. for contingencies, making a total of 70 per cent. additional power.

When the diameter of the pump and velocity of the water are given, to find the quantity discharged in gallons or cubic feet in any given time. Multiply the velocity of the water in feet per minute by the square of the pump's diameter in inches, and by ·034 for imperial gallons, or ·005454 for cubic feet, and the product will be the number of gallons or cubic feet discharged in the time nearly.

When the length of stroke and the number of strokes are given, to find the diameter of the pump and the horse-power that will pump or discharge a given quantity of water in a given time. First, multiply the number of imperial gallons of water to be discharged in the given time by 353, or the number of cubic feet by 2201, and divide the product by the velocity of the water in inches; the square root of the quotient will be the pump's diameter in inches. Second, multiply the number of gallons per minute by 10, or the number of cubic feet by 62·5, and by the perpendicular height of the water in feet, divide the product by 33,000, then add $\frac{1}{5}$th to the quotient, which will give the horse-power required. Example:—

Supposing 3,000,000 gallons of water is required in the 24 hours, the stroke being 10 feet, making 12 strokes per minute—

Gals. in the 24 hours.		mins.		
3,000,000	÷	1440	=	2083 gallons per minute.

Constant.		Stroke.		Strokes per min.		
·03409	×	10	×	12	=	4·09 divisor.

Gals. per min.

$$\frac{2083}{4\cdot09} = \sqrt{509\cdot2}$$, the square root of which is 22·6 inches, the diameter of the pump.

One-fourth more than the above is usually allowed for waste.

Again, supposing the number of gallons per minute is required—

Constant.		Square of the pump's dia.		Stroke.		Strokes per min.		
·03409	×	509·2	×	10	×	12	=	2083 gallons per minute nearly.

To find the stroke of a pump:—

Constant.		Square of the pump's dia.,		Strokes per min.		
·03409	×	509·2	×	12	=	208·2 divisor.

Gals. per min.

$$\frac{2083}{208\cdot2} = 10 \text{ feet stroke of pump nearly.}$$

Pumping water out of floating and other docks.—Given the quantity in tons of sea water (35 cubic feet to the ton), the height to which it is raised, and the time in hours that is allowed to discharge it, to find the horse-power. Divide the quantity in tons by the number of hours, which gives the quantity to discharge per hour, and this divided by 60 gives the quantity to discharge per minute; then take 14·7 as the third divisor (14·7 tons = 33,000 lbs., the weight raised 1 foot high per minute), which gives the horse-power required to raise the total quantity 1 foot high: multiply this sum by the height at which the water is discharged, and the quotient is the horse-power required to discharge the whole amount in the given time,—to which must be added the loss from friction and waste.

To find the diameter of pump required to discharge a given number of tons of sea-water in a given time, with a certain velocity (the usual speed of pump bucket being 160 feet per minute). Multiply the quantity by the constant 35, and divide the product by the speed multiplied by the time in hours, and then by 60 for minutes; the quotient is the pump area in square feet, which can be subdivided by the number of pumps that are adopted.

Method for finding the horse-power of single-acting pumping engines.—Thus supposing the water is pumped into an air vessel to a height of 252 feet, and making an allowance for the friction in the pipe—say a total height of 285 feet—the diameter of the plunger being 23 inches and the stroke 10 feet, making 10 strokes per minute, we have as follows:

	Area in sq. feet.
Diameter of the plunger, 23 inches =	2·8852

Plunger area.		Lift in feet.		Weight in lbs. of 1 cubic ft.		lbs.
2·8852	×	285	×	62·5	=	51392

Now allowing $\frac{1}{5}$th to overcome the load on the air pump and the friction of the engine, we have:

Load on the piston in lbs.		Length of stroke.		Strokes per minute.		
61670	×	10	×	10	=	6167000

$$\text{and } \frac{6167000}{33000} = 186 \text{ horse-power nearly.}$$

Approximate rule for power of Cornish engine.—A simple rule used by some engineers for calculating the quantity of water delivered from a given pump is as follows:—Let D = the diameter of the pump, then $\frac{D^2}{30}$ represents the quantity of water in gallons delivered per 1 foot stroke of pump nearly. Let S = the speed of the plunger of bucket per minute, then $S\frac{D^2}{30}$ = the number of gallons delivered per minute. Let L = the lift in feet, and the horse-power will be thus obtained: $\frac{L\ 10\left(S\ \frac{D^2}{30}\right)}{33000}$. The following is an example:—Diameter of pump = 16, stroke of pump = 7·5, number of strokes per minute = 7·5, lift = 190 fathoms = 1140 feet.

Diameter of pump. Speed.

$$\frac{16 \times 16}{30} = 8 \cdot 5 \times (7 \cdot 5 \times 7 \cdot 5) = 478 \text{ gallons per minute.}$$

$$\text{The work done} = \frac{1140 \times 10 \times 478}{33000} = 165 \text{ horse-power nearly.}$$

This rule evidently allows for waste in the pump, but one-fifth must be added to the sum for the friction of the engine.

To find the area of cylinder required to perform a given amount of work.—We may consider the mean pressure in the cylinder as from 14 to 15 lbs. per square inch, and the velocity of the piston from 80 to 85 feet per minute. It must be remembered that the pressure per square inch is derived from the actual water load divided by the area of the piston, and that one-fifth more power must be allowed for friction. Thus the pressure multiplied by the velocity equals so many foot pounds, which may be taken on an average as 1000. Therefore we divide the number of lbs. of water raised 1 foot high by 1000, and the quotient is the area of the cylinder in square inches. For example:—Suppose it be required

to find the diameter of a cylinder of a Cornish engine sufficient to raise 7,000,000 gallons of water 120 feet high in 24 hours. Multiply the number of gallons by 10 (the weight in lbs. of a gallon of fresh water), and then by the height; divide the product by the number of hours reduced to minutes, and the quotient gives the number of lbs. raised 1 foot high per minute, which divided by 1000 gives the area of the cylinder. Thus:

$$\frac{7000000 \times 10 \times 120}{1440} = 5833333 \div 1000 = 5833,$$

which equals 86 inches diameter nearly; to which must be added an allowance for the friction of the engine. The divisor used may vary, owing to the pressure and velocity, and on this account three eminent firms have used in their practice 926, 1113, and 1140 respectively; but the average of a number of Cornish engines is 771.

Steam valves for Cornish engine:—

The steam valves..	$= \frac{1}{35}$th to $\frac{1}{20}$th	of the cylinder area.
The equilibrium valves........	$= \frac{1}{35}$th to $\frac{1}{20}$th	,, ,,
The exhaust valves............	$= \frac{1}{25}$th to $\frac{1}{13}$th	,, ,,

To find the duty of an engine.—Supposing an engine required 3 lbs. of coal per indicated horse-power per hour, it is required to find the duty performed by 112 lbs., or a cwt. of coal. The horse-power being 33,000 lbs. raised 1 foot high in a minute, or 1,980,000 lbs. raised 1 foot high in an hour—then by the rule of three we have

$$\overset{\text{lbs.}}{3} : \overset{\text{lbs.}}{1980000} : : \overset{\text{lbs.}}{112} = \overset{\text{lbs.}}{73920000}$$

raised 1 foot high by a cwt. of coal per hour. Formerly the duty was estimated by the bushel of coal, weighing 94 lbs., but it is considered most convenient to adopt the 112 lbs. measure. The average duty of Cornish engines may be taken at 60,000,000 lbs. raised 1 foot high in one hour by a bushel of coal weighing 94 lbs., or 71,489,361 lbs. with a cwt. or 112 lbs.

The power required to overcome the friction of water through pipes.—When water is required to be pumped through a long line of piping an allowance is generally made for its friction in transit. The quantity of water in cubic feet per minute, and the diameter and length of the line of piping being given, multiply the square of the quantity in cubic feet by the length of the piping in feet, and divide the product by the constant 22 for pumping engine, multiplied by the fifth power of the diameter of the piping. Thus, supposing

61 cubic feet of water requires to be forced to a height of 178 feet, the length of the piping being 8145 feet and the diameter of the pipe 9 inches, we have—

$$\frac{\overset{\text{Cubic feet.}}{61 \times 61} = 3721 \times \overset{\text{Length of piping.}}{8145} = 30307505}{22 \times (9 \times 9 \times 9 \times 9 \times 9) = 1299078} = 23{\cdot}2 \text{ feet,}$$

as the additional height to be allowed for the friction, or say 24 feet in round numbers; thus 24 feet added to the height the water requires to be pumped equals 202 feet: then calculate the horse-power by the ordinary method, namely:

$$\frac{\overset{\text{Cubic feet.}}{61} \times \overset{\text{Height.}}{202} \times \overset{\text{Weight of a cubic foot.}}{62{\cdot}5}}{33000} = 23{\cdot}3 \text{ horse-power,}$$

to which add one-fourth for loss, and the product is 29 horse-power nearly, irrespective of the friction of the engine.

Formula to find the extra height to allow for friction according to the above:—

$$H = \frac{Q^2\, l}{22\, d^5},$$

where Q is the quantity in cubic feet per minute, l the length of the line of piping, and d the diameter of the pipes.

Formula to find the horse-power required to overcome the friction:

$$P = \frac{Q^3\, l}{140\, d^5}.$$

P represents the horse-power necessary to overcome the friction, l the length of the pipe in inches, Q the quantity of water to be delivered in one second in gallons, and d the diameter of the pipe in inches. The formula reads, that the cube of the quantity in gallons per second must be multiplied by the length of the line of piping in inches, dividing the product by the constant 140 multiplied by the diameter of the piping into the fifth power.

Delivery of water in pipes.—The formula is:

$$W = 4{\cdot}72 \frac{\sqrt{D^5}}{\sqrt{\frac{L}{H}}} \qquad D = {\cdot}538 \sqrt[5]{\frac{L \times W^2}{H}},$$

where D equals the diameter of the pipes in inches, H the head of water in feet, L the length of pipe in feet, and W the cubic feet of water discharged in a minute.

Hawksley's formula.—This formula is:

$$D = \tfrac{1}{15} \sqrt[5]{\frac{G^2\, L}{H}} \qquad G = \sqrt{\frac{(15\, D)^5\, H}{L}},$$

where G equals the number of gallons delivered in an hour, L the length of pipe in yards, H the head of water in feet, and D the diameter of pipe in inches.

Weight and measurement of water:—

1 cubic foot	= 62·5	lbs. avoirdupois.
1 cubic inch	= ·03617	„
1 gallon	= 10·	„
A column 12 inches high and 1 inch square...	= ·434	„
A column 12 inches high and 1 inch diameter	= ·341	„
A cylindrical foot	= 49·1	„
A cylindrical inch	= ·02848	„
11·2 imperial gallons	= 1 cwt.	
224 imperial gallons	= 1 ton.	
1·8 cubic feet	= 1 cwt.	
35·84 cubic feet	= 1 ton.	
1 cubic foot	= 6¼ imperial gallons.	
1 cylindrical foot	= 5 „	„

To find the thickness of pipes for conveying water.—Multiply the constant ·000054 by the head of water in feet, and then by the inside diameter of the pipe in inches, to which add ⅜ inch for pipes less than 12 inches, ½ inch from 12 to 30 inches, and ⅝ inch from 30 to 50 inches internal diameter, and the result gives the thickness. Thus, supposing the head of water was 600 feet and inside diameter of the pipe 15 inches,

$$\cdot000054 \times 600 \times 15 = 000\cdot486000 + \cdot5 = \cdot98,$$

or nearly 1 inch as the thickness.

PROPORTIONS OF SOCKET FOR STANDARD PIPES FOR WATER SUPPLY.

Internal Diameter.	Thickness.	Depth of Socket.	Thickness of Socket.	Space for Packing.
inches.	inch.	inches.	inch.	inch.
3	$\frac{5}{16}$	$3\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$
4	$\frac{5}{16}$	$3\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
5	$\frac{3}{8}$	$3\frac{3}{4}$	$\frac{7}{16}$	$\frac{7}{16}$
6	$\frac{3}{8}$	$3\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{16}$
7	$\frac{3}{8}$	$3\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{16}$
8	$\frac{7}{16}$	$3\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{16}$
9	$\frac{7}{16}$	4	$\frac{9}{16}$	$\frac{1}{2}$
10	$\frac{1}{2}$	4	$\frac{5}{8}$	$\frac{1}{2}$
11	$\frac{1}{2}$	4	$\frac{5}{8}$	$\frac{1}{2}$
12	$\frac{9}{16}$	4	$\frac{11}{16}$	$\frac{1}{2}$
14	$\frac{5}{8}$	4	$\frac{11}{16}$	$\frac{1}{2}$

To find the weight of cast-iron pipes.—To find the weight of a lineal foot, square the outside and inside diameters, and find the difference, then multiply the result by 2·45 lbs., which is the weight of a circular bar 1 inch diameter and 1 foot long. Supposing the pipe is 22 inches diameter outside and 20 inches diameter inside,

$(22 \times 22) = 484 - (20 \times 20) = 400 = 84 \times 2{\cdot}45 = 205{\cdot}8$ lbs. nearly.

Two flanges are generally reckoned equal to 1 foot of pipe.

Pipes for pit pumps.—The most approved form of joint for pit or pump stand pipes is the spigot and faucet, with a turned face on the flanges for making the joint, which is done by a ring of wrought

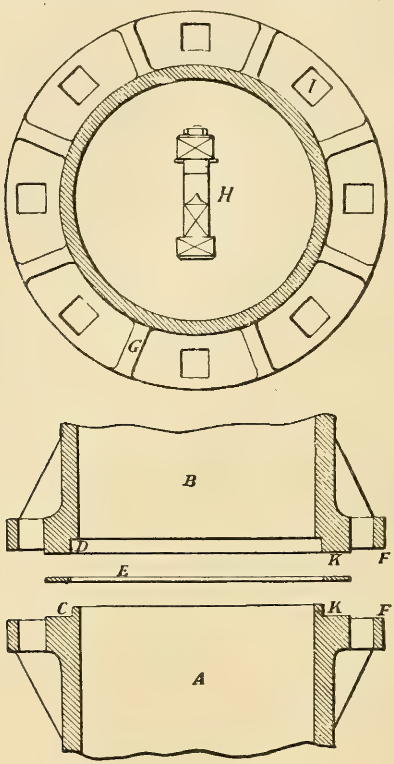


Fig. 200 A.—Pipes for Pit Pumps.

A, Bottom pipe. B, Top pipe. C, Spigot. D, Faucet. E, Ring of wrought iron. F, Flange. G, Brackets. H, Bolt and nut. I, Holes. K, Faces for joint.

iron covered with plaiding steeped in tar, and securely bolted together by means of the flanges and bolts. The spigot is accurately turned a little less in diameter than the faucet, which is bored out for its reception. The flanges are strongly bracketed to the body of the pipe, and the holes for the bolts are made slightly oblong. The length of the pipe is generally about 9 feet over the flanges, and the body is strengthened with two or more raised rings cast on.

Horse-power of an engine.—The horse-power of a condensing beam engine may be found theoretically by calculating the mean pressure taken from the steam pressure adopted and the point of cut-off determined on, allowing 12 lbs. per square inch as the amount to be derived from the vacuum. Hence,

$$\frac{\text{Area of cylinder in sq. in.} \times \text{total pressure per sq. in.} \times \text{velocity of piston in feet per minute}}{33000}$$

gives the horse-power the engine will work up to, adding to this an allowance of about one-fifth for friction.

Diameter of cylinder and length of stroke.—To find the diameter of cylinder for a given horse-power, we must first find the number of square inches to the horse-power, at the speed determined on, by dividing the constant 33,000 by the total pressure (adding one-fifth for friction) multiplied by the velocity of the piston in feet per minute. Thus,

$$\frac{33000}{\text{Total pressure} \times \text{velocity of piston in feet per minute}},$$

and the product multiplied by the total horse-power will give the full area of the cylinder in square inches. Where great exactness is required, add one-half of the area of the piston rod, then by the table of areas the diameter is easily ascertained. The stroke of the piston ranges from 2 to 2½ times the diameter of the cylinder.

Speed of piston (varying with the stroke):—

2 ft.	0 in.	stroke	=160	feet per minute.	4 ft.	6 in.	stroke	=207	feet per minute.
2	6	,,	=170	,,	5	0	,,	=215	,,
3	0	,,	=180	,,	6	0	,,	=228	,,
3	6	,,	=189	,,	7	0	,,	=245	,,
4	0	,,	=200	,,	8	0	,,	=256	,,

Opening of port by valve.—The opening of the port by the valve is found by multiplying the area of the cylinder in square inches by the speed in feet per minute, dividing the product by the constant 10,000. The port should be made in excess of this, so as to give a free exhaust; the breadth depends on the length of the port, one-twentieth of the area of the cylinder may be allowed in all cases. For the exhaust port multiply the area of the supply port by 1·5, and for the length of port multiply the diameter of the cylinder by ·6.

RULES FOR THE BEAM ENGINE.

The beam.—The length of the beam should not be less than three times that of the stroke, and its breadth one-half of the stroke; for the breadth at the ends multiply the breadth at the middle by ·4. To find the thickness of web at the centre multiply the total pressure on the piston—*i.e.*, steam and vacuum—by one-half of the length of the beam in inches, and divide the result by the constant 500 into the depth in inches; the quotient is the sectional area in square inches for cast iron.

Wrought-iron tubular beams:—

l = length .... 28 feet 8 inches.
d = depth .... 5 ,, 6 ,,
a = area of bottom flanges .... 56·67 square inches.
C = constant 80
W = breaking weight in tons; hence

$$W = \frac{56 \cdot 67 \times 5 \cdot 5 \times 80}{28 \cdot 66} = 870 \text{ tons,}$$

as the breaking weight in the middle. The load on the beam being from 85 to 90 tons, we may safely consider the ratios of strength as 870 : 90, or nearly 10 to 1. The thickness of sides for a beam of the above dimensions is ⅜ inch, supported between the flanges with T-iron over the joints, and corresponding strips outside; upper and lower webs or flanges 2 feet wide, with four plates in each, ¾ inch thick, rivetted to the sides with double angle iron. The centre boss is cast with a plate, which is rivetted to the sides; the end and intermediate bosses have also cast-iron plates. Instead of the box form of beam, the side plates are sometimes made of sufficient strength, having no angle irons at the top or bottom, but merely secured with bolts and nuts, and sometimes rivetted to the cast-iron bosses. The diameter of the main gudgeon is generally one-fourth of the diameter of the cylinder, and for the piston-rod gudgeon divide the cylinder diameter by 6·5; or they may be calculated taking them as round beams loaded in the middle.

To find the versed sine described by the beam of an engine.—Dividing the square of the stroke of the engine by 8, multiplied by the radius of the beam, gives the versed sine nearly, viz., $S^2 \div (8 \times R) =$ versed sine.

Air pump and condenser.—The air pump has generally a stroke

of one-half of the travel of the steam piston. To find its cubical contents, divide the cubical contents of the steam cylinder by 4·3. When the stroke of the pump equals one-half that of the steam piston, to find the diameter of the pump, in usual cases, multiply the diameter of the cylinder by ·7. The cubical contents of the condenser should be about twice the capacity of the air-pump.

Cold-water pump and injection water.—To determine the size of the cold-water pump we must first ascertain the quantity of water required for condensation. This is found by multiplying the temperature of the steam by ·0034; or approximately 0·8 cubic foot, or 5 gallons, are required per nominal horse-power. Multiply this number by the nominal horse-power of the engine, and then by the constant 2200; divide the result by the velocity of the pump bucket in inches per minute, and the square root of the quotient is the diameter of the pump. When the stroke of the pump is one-half of that of the steam piston, the usual diameter allowed for the pump is found by multiplying the diameter of the cylinder by 0·3. The area in square inches of the injection valve should be from $\frac{1}{10}$th to $\frac{1}{12}$th the number of cubic feet in the steam cylinder.

The feed pump.—To find the water required to be delivered by the pump, multiply the cubic contents in feet of steam in the cylinder for an entire revolution by the number given in the table of cubic inches of water required to raise a cubic foot of steam at the desired pressure, and the result will give the contents of a single-acting pump in cubic inches; a little more may be allowed for waste, &c., but when the steam is cut off soon in the cylinder no additional allowance will be required.

TABLE OF THE PROPORTION OF WATER TO STEAM.

Pressure of steam per square inch.		Cubic inches of water in a cubic foot of steam.	Pressure of steam per square inch.		Cubic inches of water in a cubic foot of steam.
1	=	1·099	45	=	3·700
5	=	1·350	50	=	3·981
10	=	1·658	55	=	4·256
20	=	2·258	60	=	4·535
25	=	2·552	65	=	4·812
30	=	2·842	70	=	5·052
35	=	3·130	75	=	5·317
40	=	3·415	80	=	5·650

The diameter of the valves is found by multiplying the diameter of the plunger by 0·6.

Piston rod and connecting rod.—To find the diameter of the piston rod for compressive strain, multiply the area of the cylinder by

the steam pressure, and divide by 2240, which gives the area of the rod; and for tensional strain divide by 4000, which gives the area at the weakest part. These proportions will be sufficient for all the parts subjected to direct strain. The area of the connecting rod straps equals the area of the piston rod; the thickness of the strap at the keyways must be more according to the area cut out for the key. The depth of jib and cotter equals two-thirds of the diameter of the connecting rod at the ends; the thickness of the jibs and keys equals one-fourth of the rod at the ends; taper of the key equals ½ inch to the foot; keyway from end of butt equals the breadth of the jibs and cotters.

Crank shaft.—To find the diameter of the crank shaft when made of wrought iron, multiply the length of the crank in inches from centre to centre by the total pressure on the piston, and divide the sum by 1206; the cube root of the quotient will be the diameter of the shaft.

Crank of wrought iron.—The diameter of the crank pin will be found by multiplying the diameter of the cylinder by ·16; for the length of the pin, multiply the diameter of the cylinder by ·22. The diameter of the eye for the crank pin is twice the diameter of the pin. The length of the boss at the shaft is equal to the diameter of the shaft; and for the thickness of the metal around the shaft multiply the diameter of the shaft by ·37. The breadth of the web at the crank-pin end and journal is three-fourths of the diameter of the respective bosses, and its thickness is five-eighths of their width. These proportions are for low-pressure engines, with a steam pressure of 30 lbs. or so per square inch.

Crank of cast iron.—The diameter of the crank pin is the same as for wrought iron, and also the length of the pin. The diameter of the eye for the crank pin is two-and-one-half times the diameter of the pin. The length of the boss at the shaft equals the diameter of the shaft, and its diameter is twice the diameter of the shaft. The breadth of the web at the crank pin and journal bosses is three-fourths of the diameter of the respective bosses, and its thickness is one-half of the diameter of the shaft, with a feather at the back tapering from the large boss to the crank-pin boss, in thickness one-half of that of the web.

Fly wheel.—The diameter of the fly wheel is generally from three-and-a-half to four times that of the stroke of the engine. The velocity of the periphery should always exceed the velocity of the

periphery of the stones of a flour or other mill, to prevent back lash. To find the weight of the rim in cwts. multiply the constant 1366 by the horse-power of the engine, and divide the product by the mean diameter multiplied by the number of revolutions per minute, and the quotient is the weight. To find the thickness of the ring when the breadth is given, in the first place find the area of the ring in square inches, then divide the weight in lbs. by the area multiplied by ·263, and the quotient is the thickness in inches. The breadth of the rim for large wheels is generally $\frac{1}{24}$th of the diameter of the wheel, to $\frac{1}{14}$th for small wheels.

The governor.—The point of suspension of the arms should be as near the centre of rotation as possible, and the working angle should never exceed 45°; the diameter of the balls varies from 4 to 9 inches. To find the number of revolutions, divide 375 by the square root of the pendulum, or vertical distance from the point of suspension to the working plane of the centre of the balls, and one-half of the quotient will be the number of revolutions required. When the revolutions are given, to find the length of the pendulum. Divide 375 by twice the number of revolutions per minute, and the square root of the quotient will be the length required; or otherwise, divide the constant 187·5 by the square root of the pendulum, which will give the number of revolutions. Thus, supposing the vertical height is 36 inches, the square root = 6 inches, we have—

$$\frac{187{\cdot}5}{6} = 31{\cdot}25 \text{ revolutions.}$$

Given the number of revolutions, to find the length of the pendulum from the centre of the working plane of the balls to the centre of suspension. Divide 187·5 by the number of revolutions, and the square of the quotient will be the length of the pendulum:

$$\frac{187{\cdot}5}{31{\cdot}25} = 6^2 = 36 \text{ inches long.}$$

Formulæ for safety-valve levers:—

$$(1)\ \frac{\text{Weight or pressure on the valve} \times \text{distance of valve from stud}}{\text{Total length of lever from stud}} = \text{weight.}$$

$$(2)\ \frac{\text{Weight or pressure on the valve} \times \text{distance of valve from stud}}{\text{Weight}} = \text{total length of lever.}$$

$$(3)\ \frac{\text{Weight on lever} \times \text{total length of lever from stud}}{\text{Distance of valve from stud}} = \text{total pressure on valve.}$$

This is when the valve is between the stud or pin and the weight on lever. When great exactness is required, subtract the weight

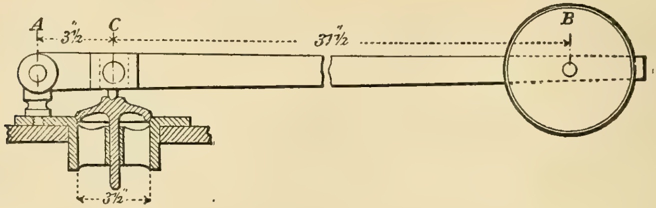


Fig. 200B.—Safety Valve, with Lever and Weight.

A, Stud. B, Weight. C, Valve.

of valve and the effective leverage or weight of lever from the total (steam lbs.) pressure on the valve. Examples:—

Supposing the pressure of the steam in the boiler is 30 lbs. per square inch above the pressure of the atmosphere, giving a total of 288·61 lbs. on the valve—and the length from A to B is 35 inches, and from A to C 3½ inches—we have,

$$\frac{288{\cdot}6 \times 3{\cdot}5}{AB = 35} = \text{weight on B} = \text{say } 28{\cdot}86 \text{ lbs.},$$

$$\frac{288{\cdot}6 \times 3{\cdot}5}{B = 28{\cdot}86} = \text{B from A} = \text{say } 35 \text{ inches},$$

$$\frac{28{\cdot}86 \times 35}{AC = 3{\cdot}5} = \text{total pressure on the valve} = 288{\cdot}6 \text{ lbs.},$$

which gives the total load on the valve; to be more accurate, the weight of the valve and the effective leverage must be subtracted from 288·6, the total (steam lbs.) pressure on the valve.

WATER-PRESSURE ENGINES.

In 1846 the first hydraulic crane was erected at Newcastle-on-Tyne, for discharging ships, the supply of water being obtained from the mains connected with the town service reservoirs. Afterwards one was erected at Liverpool, and another at the new dock at Grimsby. The Liverpool crane, like the Newcastle one, was supplied with water from the town mains; but at Grimsby a tower was built with a tank into which the water was pumped by a steam engine. In the former cases the irregularity of pressure consequent

on the varying drain upon the pipes for the ordinary consumption proved a serious disadvantage; but this drawback was not experienced at Grimsby, where the tank upon the tower furnished an uninterrupted supply. In the absence of a natural head of water, with pipes laid for conveying it to a lower situation, the erection of water towers was a serious obstacle in extending the principle of the hydraulic crane, and engineering ingenuity resorted to another form of head, which possesses the advantages of being applicable at a moderate cost in nearly all situations, and of lessening the size of the pipes and cylinders by affording a pressure of greatly increased intensity. The apparatus by which this is effected has been named the "accumulator," because of its accumulating the power exerted by the engine in charging it. The accumulator is in fact a reservoir giving pressure by load instead of by elevation, and its use is to equalize the duty of the engine in cases where the quantity of power to be supplied is subject to great and sudden fluctuations. In the application of water-pressure machinery, where an artificial head of water has to be obtained, the real source of power is the steam engine employed in pumping the water into the accumulator, and the water acts simply as a convenient means of storing up the power of the engine, and applying it whenever wanted at the distant points where the work has to be done. We may take as an example of this the Victoria Docks in London, where the area over which the power is extended is so great as to require 4 miles' length of mains to convey the water to the several cranes, hoists, and to the lock-gates.

In Hastie's variable water-power engine the quantity of water is regulated to the work done automatically. There are two or more oscillating cylinders rocking on trunnions at their lower ends, the pistons being solid plungers, and centered on a crank pin which is free to move in a slide, so that the throw becomes variable according to the demand on the engine.

THE ACCUMULATOR.

The accumulator consists of a large cast-iron cylinder A (Fig. 201), fitted with a plunger B, from which a loaded case C is suspended to give pressure to the water injected by the engine. The load upon the plunger B is usually such as to produce a pressure in the cylinder equal to a column of water 1500 feet in height, and the cylinder is

made large enough to contain the quantity of water which can be required from it at once by the simultaneous action of all the hydraulic machines connected with it. If, however, the engine pumps more water into the accumulator than the hydraulic machines require, the plunger rises and makes room in the cylinder for the surplus; and when, on the other hand, the supply from the engine is less than the quantity required, the plunger with its load descends and makes up the deficiency out of the store. The accumulator serves also as a regulator to the engine, for when the plunger rises to a certain height it begins to close the throttle valve in the steam pipe, so as gradually to reduce the speed of the engine, until the descent of the plunger again requires an increase of power. The introduction of the accumulator removed all the obstacles to the extension of water-pressure machinery, which has been now practically tested in nearly all the principal docks and in many of the government establishments in this country. This class of machinery has also been adopted in many of the principal railway stations, not only for cranage, but also for working turntables, traversing machines, waggon-lifts, hauling machines, &c. It is also extensively used for raising and tipping waggons in the shipment of coal, for opening and closing bridges, and for many other purposes.

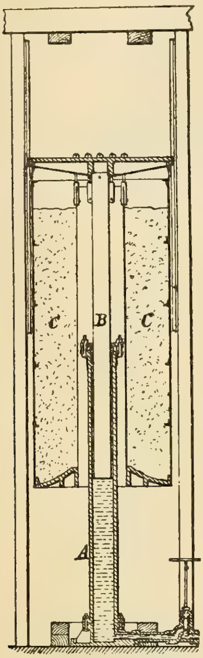


Fig. 201.—Vertical Section of Accumulator.—A, Cylinder. B, Plunger. C, Loaded case.

PUMPING ENGINE FOR CHARGING THE ACCUMULATOR.

The most approved form of the pumping engine for charging the accumulator is that of two high-pressure cylinders fixed horizontally, with double-acting pumps directly connected with the piston rods; the form of pump being the solid bucket and plunger system. In the arrangement shown (Fig. 202) the OUT stroke of the pump forces the water contained in the annular space surrounding the plunger E into the accumulator, while a further supply of water enters behind the piston F through the suction valve G. In the IN stroke the water behind the piston is discharged through the

delivery valve D, half of it passing round into the annular space on the other side of the piston, the remaining half being forced into the accumulator. As the area of the plunger E is exactly half that of the piston F, each stroke of the pump delivers the same quantity of water into the accumulator. Much difficulty has been experienced to secure proper joints for the pipes of hydraulic machinery; no plan appears to stand so well as a small ring of gutta percha

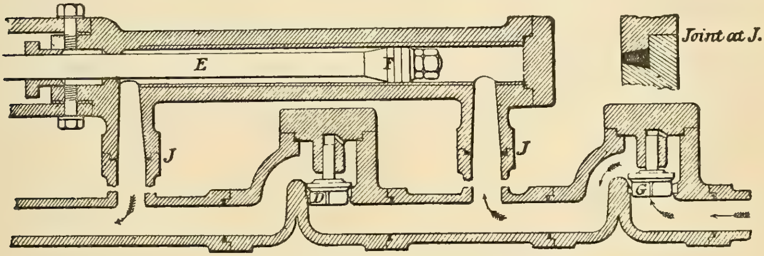


Fig. 202.—Longitudinal Section of Force Pump.
D, Delivery valve. E, Plunger. F, Piston. G, Suction valve. J, Gutta-percha ring joint.

compressed into a recess formed on the end of one pipe, with a projection on the adjoining pipe accurately turned to fit the recess, like a spigot and faucet.

Rivetting, both of boilers, girders, and shipwork, is now in many cases carried out by hydraulic pressure through the action of accumulators, loaded as high in some cases as 1500 lbs. per square inch, india rubber or flexibly jointed metal pipes being used to convey the water to the working parts.

WATER WHEELS.

Water wheels may be classed as vertical and horizontal, of these the vertical class may be subdivided into undershot, overshot, and breast wheels, whilst the turbine form represents the horizontal class. The undershot wheel is simply the old form of water wheel, made of wood, with radial float-boards, on which the water presses as it flows past. The efficiency or ratio of the useful to the total work is small in such wheels, being only about $\frac{1}{3}$. In the overshot or breast wheel the water is led on at or near the top, and the floats are made of a bucket form; the weight of the water is in this manner taken advantage of as well as the impulse due to velocity. The efficiency of such wheels is about $\frac{6}{10}$ to $\frac{3}{4}$.

The turbine form of wheel is very suitable for high falls where a great velocity of flow can be obtained, and is not affected by "back-

water" as the vertical wheels are. There are several forms of such wheels, depending upon the direction in which the water is allowed to impinge upon the vanes or blades. These vanes are curved, and it is of importance that the water should be directed upon them in such a manner as to cause as little shock as possible; the propelling action being due to the pressure and reaction on the vane due to the gliding of the water along its surface. Curved vanes are found in this manner to be more efficient than flat surfaces, their surfaces being in the direction of the resultant of the lines of motion of the jet and vane. Turbines are now largely used on natural falls, notably so in America and in France and Switzerland.

HYDRAULIC CRANE.

Of the various applications of water pressure, the most common is that of a hydraulic press with a set of sheaves used in the inverted order of blocks and pulleys, with the object of obtaining an extended motion in the chain from a comparatively short stroke of piston. The general arrangement of the machinery for working such a crane may be described as follows:—The pressure cylinder A (Fig. 203) is fixed horizontally below the surface of the ground in a chamber at the foot of the crane, and is fitted with the ram B, carrying the pulleys C at its outer extremity. The lifting chain is made fast at one end to the cylinder A, and passes alternately round the movable pulleys C and the pulleys D at the inner end of the cylinder; and is then led round the guide pulley E up to the crane post F, and along the jib to the load. The motion of the lifting chain is controlled by means of the handle G, acting upon the inlet and outlet valves, which are kept closed by the weights H and I; by opening the inlet valve H (Fig. 204) the water is let into the cylinder A from the pressure pipe J, and acting on the plunger raises the load; by opening the outlet valve I the water escapes from the cylinder into the exhaust pipe K, allowing the load to descend. The travel of the ram B in the outward stroke is prevented from exceeding the proper limit by the pulley block C coming in contact with a stop connected with the handle G, which closes the inlet valve H, and prevents the load from being lifted too high. The return stroke of the ram is effected by the load suspended from the chain; and in the absence of any load, a small supplementary ram L is employed to force the main ram B back, the slack chain being made to run out by the permanent weight M.

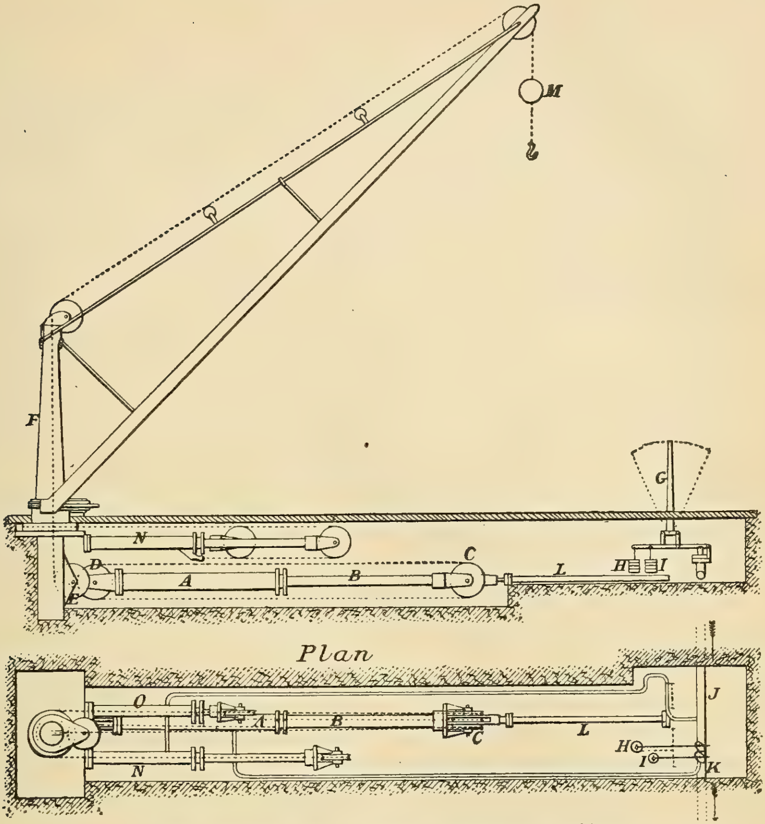


Fig. 203.—Hydraulic Crane. General Arrangement of Machinery.

A, Pressure cylinder. B, Ram. C and D, Pulleys. E, Guide pulley. F, Crane post. G, Handle for valves. H and I, Weights. J, Pressure pipe. K, Exhaust pipe. L, Supplementary valve. M, Permanent weight. N O, Cylinders and plungers for turning the crane.

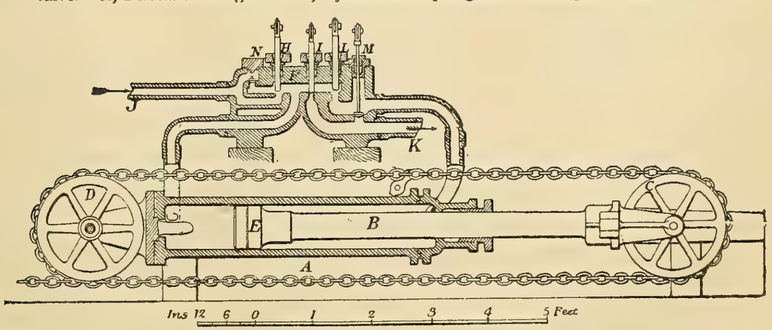


Fig. 204.—Cylinder and Valves for Double-power Hydraulic Crane.

A, Cylinder. B, Ram. C and D, Pulleys. E, Piston. F, Valve chest. H, Inlet valve. I, Outlet valve. J, Pressure pipe. K, Exhaust pipe. L, Valve for higher power. M, Valve. N, Relief valve.

To meet the variation of load it was formerly the practice to combine three of the pressure cylinders so as to act either separately or collectively upon the lifting chain; but a variation of power is now obtained with a single-bored cylinder, fitted with a combined piston and ram, as follows:—A (Fig. 204) is the cylinder, fitted with the piston E and ram B; the water from the accumulator enters the valve chest F through the pressure pipe J and the inlet valve H. For the lower power the water is admitted to both sides of the piston E by opening the valve L, in which case the power exerted and the water expended are proportionate to the area of the ram B.

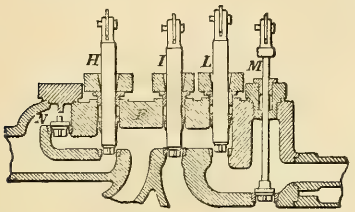


Fig. 205.—Detail of Valves for Cylinder of Double-power Hydraulic Crane. — F, Valve chest. H, Inlet valve. I, Outlet valve. L, Valve for higher power. M, Valve. N, Relief valve.

For the higher power the valve L is closed and the valve M opened, so that the front side of the piston E is thrown open to the exhaust K, and the result, both as regards power and expenditure, is then proportionate to the full area of the piston E. It is seldom necessary to have more than these lower and higher powers; but where a third or less power is required, a smaller ram is used with the other. For lowering the load the valves H and M are closed and the outlet valve I opened, allowing the water to escape from the cylinder A into the exhaust pipe K; at the same time the valve L is opened to allow the water to follow up the piston in the inward stroke. The packing of the solid piston A is held in position by means of a ring of metal B, and secured to the piston by stud bolts and nuts, and consists of a cupped leather washer C, which is pressed against the side of the cylinder by the hydraulic pressure.

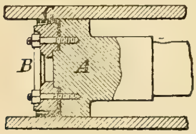


Fig. 206.—Piston and Cupped Leather for Cylinder of Double-power Hydraulic Crane.—A, Piston. B, Ring with bolts. C, Cupped leather.

In hydraulic cranes the power is applied not only for lifting the load, but also for swinging the jib, which is effected by means of a rack or chain acting on the base of the movable part of the crane, connected either with a cylinder and piston, or with two single-acting cylinders applied to produce the same effect by alternate action; as shown, the two cylinders N and O (Fig. 203) are fitted with rams, working by a chain passing round the base of the crane post F. The motion

is controlled by means of a slide valve worked by a handle situated alongside the handle G, so that while the water is admitted to one cylinder the other is open to the exhaust. The travel of the rams is limited by means of a tappet rod connected with the handle of the slide valve, whereby the crane is prevented from being turned round too far. Small hydraulic rotary engines have been introduced for working cranes, and in many cases they can be easily attached to existing hand cranes.

The absence of any sensible elasticity in water renders the motions resulting from its pressure capable of the most perfect control by means of the valves which regulate the inlet and outlet passages; but this property, which gives so much certainty of action, tends to cause shocks and strains to the machinery by suddenly resisting the momentum acquired by the moving parts. Take, for example, the case of a hydraulic crane swinging round with a load suspended from the jib: the motion being produced by the water entering into one cylinder and escaping from the other, it is obvious that if the water passages be suddenly closed, the ram, impelled forward by the momentum of the loaded jib, but met by an unyielding body of water deprived of outlet, would be brought to rest so abruptly as to cause in all probability some damage to the machine. So also, in lowering a heavy weight, if the escape passages were too suddenly closed, a similar risk of injury would arise from the sudden stoppage of the weight. But these liabilities to injury are effectually removed, in the case of a single-acting cylinder, by fitting a relief valve in connection with the water passages, consisting of a small clack valve N opening upwards against the effective pressure, so as to permit the pent-up water in the cylinder to be forced back into the pressure pipe, whenever it becomes subject to a compressive force exceeding the pressure given by the accumulator; and in the case of a double-acting cylinder fitted with a piston and slide valve, or where two single-acting cylinders with rams working alternately are controlled by a slide valve—as in the instance of the cylinders N and O—for turning the crane, relief valves are fitted in connection with the slide valve. These consist of four small leather flap valves (Fig. 207), with metal pieces at the top and bottom. The passages PP communicate with the pressure pipe J, and the passages E E with the exhaust K. When the slide valve is moved in the direction of the arrow the pressure is first cut off from the port R by the top of the valve, the port S being still open to the

exhaust K; at the same instant the flap valve T opens upwards and allows a small quantity of water to pass from the exhaust K into the port R to follow up the ram until brought to rest. When the slide valve arrives at the central position as shown, the port S is closed to the exhaust, and the pressure in it being increased by the further motion of the ram before it is completely stopped, the second flap V is raised, and a small quantity of water forced back into the passage P communicating with the pressure pipe J. When the slide valve is moved in the opposite direction, the two remaining relief valves are brought into action in the same manner. By these means all risk of concussion is avoided, and perfect control over the machine is combined with great softness of action.

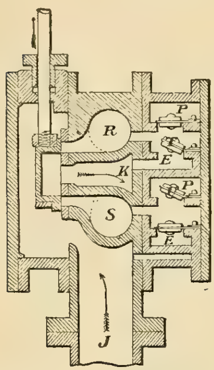


Fig. 207.—Section of Slide Valve & Relief Valves for Hydraulic Crane.

E E, Exhaust passages. J, Pressure pipe. K, Exhaust. P P, Pressure passages. R and S, Ports.

DOCK GATES.

The method generally adopted for opening and closing dock gates by means of hydraulic pressure consists in applying to each gate a pair of cylinders with rams and multiplying sheaves, similar to those used for the hoisting apparatus in hydraulic cranes. One of these cylinders opens the gate and the other closes it; and the whole of the machinery is placed in chambers beneath the ground. The water is admitted from the pressure pipe J to the cylinder A (Fig. 208) through the inlet valve H by means of the handle G; the same motion of the handle also opens the outlet valve of the other cylinder B. The opposite motion of the handle G opens the outlet valve I, allowing the water to escape from the cylinder A into the exhaust pipe K, and at the same time admits the pressure to the cylinder B. A stop M connected with the handle G prevents the ram from travelling too far in the out stroke, by closing the inlet valve; and the return stroke of the ram is effected by means of the weight L. This arrangement has been applied to several of the London and Liverpool Docks, as well as to some others throughout the country.

In Fig. 209 we give an engraving of the general plan of a

dock entrance which has been adopted in some instances, and

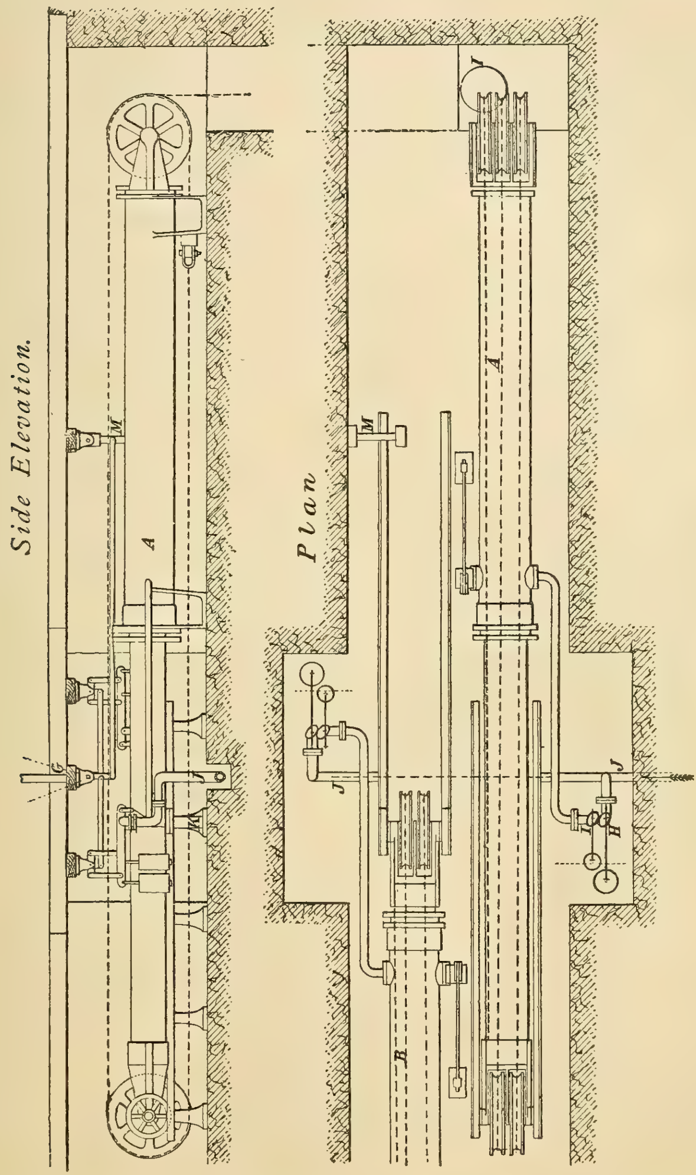


Fig. 208.—Arrangement of Water-pressure Cylinder for Opening and Closing Dock Gates.

A and B, Cylinders. G, Handle. H and I, Valves. J, Pressure pipe. K, Exhaust pipe. L, Weight. M, Stop.

found to answer extremely well. Instead of connecting the hauling cylinders with each gate, a line of shafting A, driven by a small

water-pressure engine B, is laid beneath the surface of the ground, parallel with the coping on each side of the entrance, and by means of clutches is thrown into or out of gear with each gate crab. A

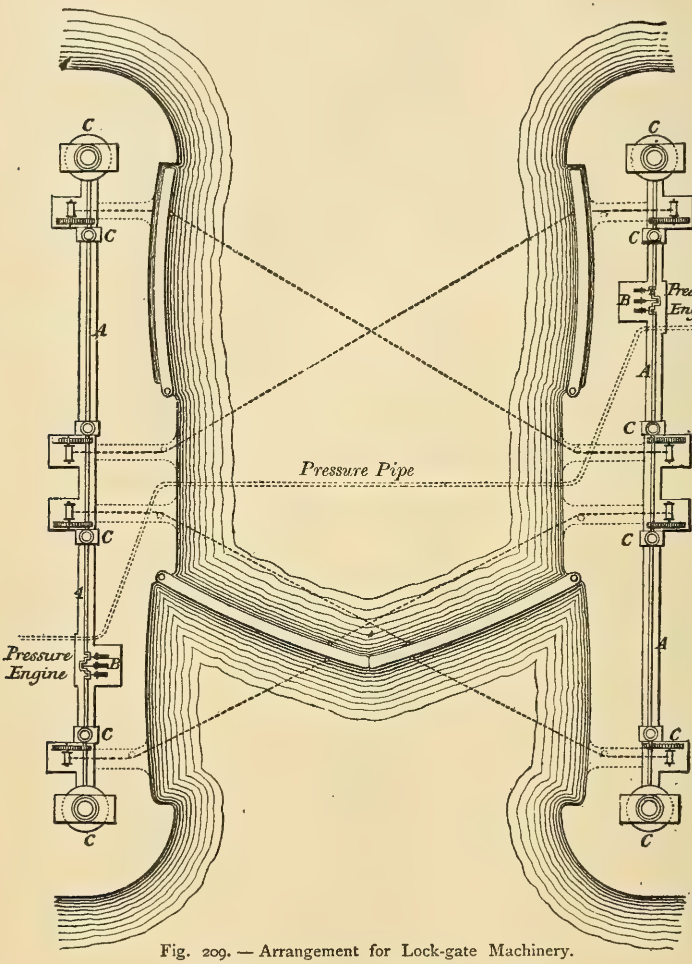


Fig. 209. — Arrangement for Lock-gate Machinery.

A, Shafting. B B, Pressure engines. C C, Capstans.

wire from the engine extends the whole length of the snafting, so that the engine can be regulated from the point where the work has to be done. A more recent method is to attach a separate engine to each crab, and also to the sluices; and in some instances these engines have been fitted to existing machines without interrupting the traffic. The rapidity with which dock gates can be

opened and closed by these appliances is limited only by considerations of safety to the gates, the time taken in actual practice being about two minutes. In nearly all the cases in which hydraulic pressure has been applied for the moving of dock gates, it is also used for opening and closing the levelling shuttles, and in many cases also for working the capstans. The former purpose is effected by the direct application of a cylinder and piston fixed above the shuttle: and the latter is accomplished by throwing the capstan C into gear with the shafting A.

WATER-PRESSURE ENGINES FOR DOCK GATES, &c.

These engines consist of a combination of three oscillating cylinders, working cranks inclined 120° to one another. The cylinders A (Fig. 210) are fitted with plungers B, instead of pistons, and are therefore only single-acting. The slide valves V are worked by the oscillation of the cylinders, communicated through the levers L. When the back end of the cylinder is depressed, the slide valve is lowered, and allows the water to enter from the pressure pipe P through the pipe C to the cylinder, where it acts upon the plunger in the out stroke; and in the return stroke the back end of the cylinder is raised, the cylinder port C is closed to the pressure pipe P, and open to the exhaust E. A small relief valve is fitted to the cylinder pipe C, opening against the pressure, which prevents any shock when the communication with the exhaust is closed at the end of the return stroke. These engines have occasionally been made with pistons, so as to be double-acting; but for the great pressures employed where accumulators are used, the single-acting arrangement with plunger is preferred. It will be observed that with the arrangement of cranks dividing the path into three equal parts, there is no liability of the engine stopping on the "dead centre," as it is termed, the one crank assisting the other over the extreme points.

In working swing bridges by means of water pressure, a central press is generally applied to lift the entire bridge clear of its supports, and it is then turned by an application similar to that used for swinging a crane. An example of a swing bridge on this principle is seen at Wisbech, having an opening of 85 feet, arranged for a double roadway in one leaf, weighing about 450 tons. The power is derived from an accumulator charged by a hand force pump, and notwithstanding its great length and weight the bridge

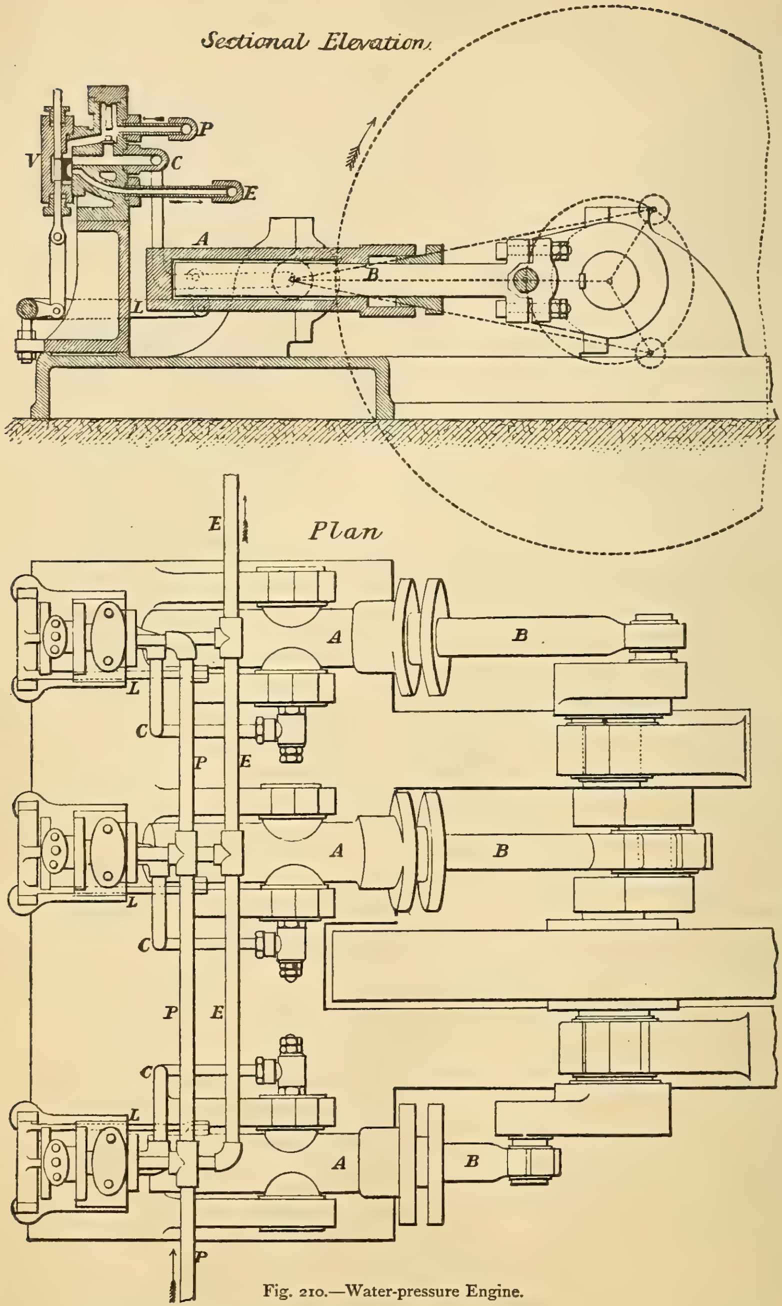


Fig. 210.—Water-pressure Engine.

A A, Cylinders. B B, Plungers. C, Pipe to cylinder. E, Exhaust pipe. L, Lever for working slide valve. P, Pressure pipe. V, Slide valve.

can be lifted and turned in less than two minutes. The plan of using an accumulator charged in this way has been adopted for a railway drawbridge near Caermarthen; and it can be applied to many other purposes requiring a concentrated exertion of power with intervening periods of inaction.

One application of water pressure with an accumulator, for the purpose of rapidly lifting or lowering heavy loads, calls for special notice because of its growing importance. We refer to vertical hoists at the landing stations of steam ferries, where the traffic of a railway is required to be passed over a river or estuary not spanned by a bridge. The traffic of the Aix-la-Chapelle, Düsseldorf, and Ruhrort Railway is by this means shipped and unshipped at the ferry across the Rhine; and such is the rapidity and facility of the operation that a train of twelve coal waggons, weighing collectively 133 tons, can be transferred from the deck of the steamer to the railway, a height of about 20 feet, in twelve minutes. Each hoist lifts two waggons at a time, and raises its load in ten or twelve seconds. These hoists are so arranged as always to accommodate themselves to the level of the boat, and also to stop at the exact level of the railway.

WATER POWER FROM NATURAL FALLS.

Having said this much on that branch of the subject which embraces the two principles of accumulation and transmission of water power, we will now notice the applications of water pressure as derived from natural falls. When the moving power consists of a natural column of water, the pressure rarely exceeds 250 or 300 feet; and in such cases, to produce rotary motion, a pair of cylinders and pistons are employed, with slide valves resembling in some measure those of a high-pressure engine, but having relief valves to prevent shock at the return of the stroke. Where the engine is single-acting, with plungers instead of pistons, as in the water-pressure engine already described, the relief valves are greatly simplified, and indeed are reduced to a single clack in connection with each cylinder, opening against the pressure, as the relief valve in the valve chest of the hydraulic crane. The water engines erected at the lead mines at Allenheads, in Northumberland, present an example of the utilization of natural falls in this country. These engines are used for the various purposes of crushing ore,

raising materials from the mines, pumping water, giving motion to machinery for washing and separating the ores, and driving a saw-mill and the machinery of a workshop. Small streams of water, which flowed down the steep slopes of adjoining hills, have been collected into reservoirs at elevations of about 200 feet, and pipes have been laid from them to the engines. Water-pressure machinery is invaluable in such a hilly district, where steam power is almost impracticable in a commercial point of view, from the great cost of conveying coals to the works.

An application of hydraulic machinery in situations where falls of sufficient altitude for working water-pressure engines cannot be obtained has been carried out at these mines, which deserves special notice. For the purpose of draining an extensive district, and searching for new veins, a drift way or open level nearly 6 miles in length was cut. This drift way runs beneath the valley of the Allen, nearly in the line of that river, and upon its course three mining establishments have been erected. At each of these power was required for the various purposes already mentioned, and it was desirable to obtain this power without resorting to steam engines. The river Allen was the only resource, but its descent was not sufficiently rapid to permit of its being advantageously applied to water-pressure engines; it abounded, however, with falls suitable for overshot wheels, and it was determined to employ the stream, by means of such wheels, in forcing water into accumulators, and then transmitting by pipes the power thus stored to the numerous points where it was required. In this arrangement intensity of pressure takes the place of magnitude of volume, and the power derived from the stream assumes a form susceptible of unlimited distribution and division, and capable of being utilized by small and compact machines.

A somewhat similar plan is also adopted at the coaling establishment for the navy at Portland Harbour. The object in this case is to provide power for working hydraulic cranes and hauling machines for coaling war steamers. A reservoir on an adjoining height affords an available head of upwards of 300 feet; but in order to diminish the size of the pipes, cylinders, and valves connected with the machinery, and also to obtain greater rapidity of action, a hydraulic pumping engine and accumulator are interposed, so as to intensify the pressure and diminish the volume of water acting as a medium of transmission.

HYDRAULIC MACHINERY FOR WAREHOUSING GRAIN AT THE LIVERPOOL DOCKS.

The dock around which the blocks of warehouses on the Liverpool side of the river are situated, shown in the general plan Fig. 211, is 570 feet long, 230 feet broad at one end, and 180 feet at the other. Three sides of it are occupied by separate blocks of warehouses, connected by wrought-iron bridges. The blocks on the east and west sides are 650 feet long and 70 feet wide, and that on the north end is the same width and 185 feet long. Each block contains five stories, as shown in the transverse section, Fig. 215; above the fifth or top storage floor, and partly in the roof, is placed the machinery floor; and below the quay level are wells and arched subways for the reception of the underground machinery. There are five discharging berths for large vessels, one at the north block and two each at the east and west blocks; and additional accommodation is provided for small vessels. In the centre or north block is placed the steam engine A, of 370 horse-power, which in addition to driving the whole of the machinery in the warehouses, supplies power for working the lock machinery and the bridges. These consist of two bridges of 60 feet span and one of 50 feet, twelve sluices, ten powerful ship capstans, and twenty-four machines for opening and closing the lock gates.

The principal processes required to be performed by the machinery in the warehouses are:—Discharging grain in bulk direct on to the quay or into the warehouses;—hoisting grain in bags or casks on to the quay;—discharging ordinary merchandise direct on to the quay or on to any floor in the warehouses, and loading outward-bound vessels;—lifting and lowering sacks or other merchandise on platform elevators and jiggers, to or from any floor;—elevating, screening, weighing, and distributing grain in bulk, and conveying it to and from all parts of the warehouses, and outwards for delivery into ships or waggons;—and transferring grain from one part of the warehouses to any other part.

The two accumulators which generate the water pressure employed as the medium for conveying power to the machinery are situated at C C in the general plan Fig. 211, at each end of the centre or north block of building; and between the west block and the river entrances a large auxiliary accumulator is placed. The two accumulators in the north block are each weighted with a load of 70 tons,

acting on a ram 17 inches in diameter, with a vertical range of 17 feet; and the auxiliary accumulator is loaded with 100 tons, acting

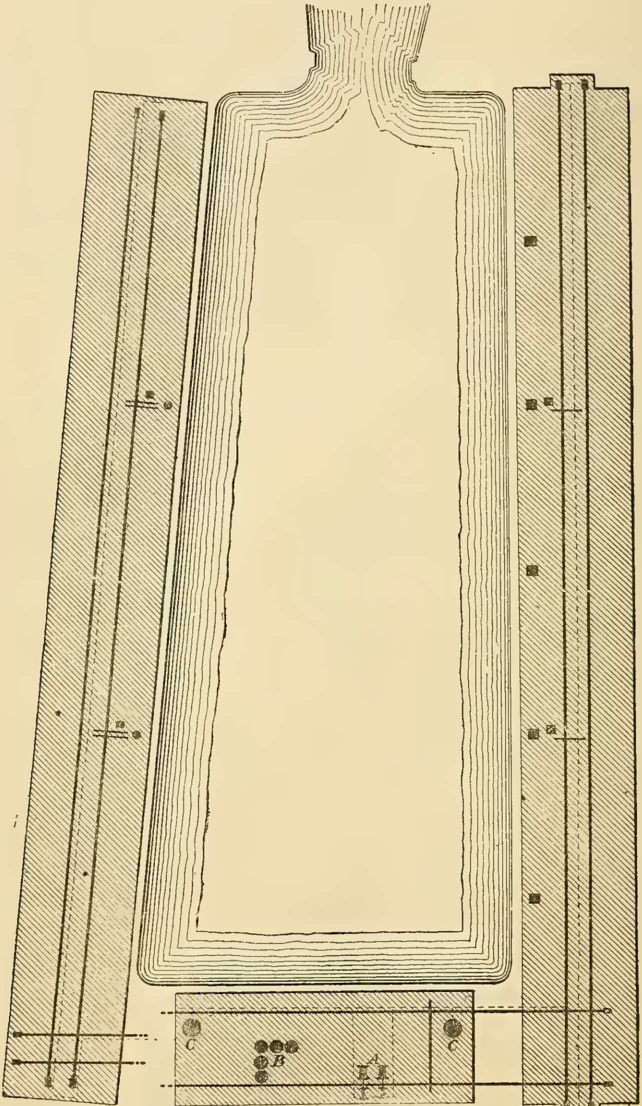


Fig. 211.—General Plan of Warehouse.
A, Steam engine. B, Boilers. C C, Accumulators.

on a 20-inch ram having a range of 23 feet. The water pressure is conducted through cast-iron main pipes, varying from 6 inches to

3 inches in diameter, and wrought-iron branch pipes convey it from the mains to the several machines. In order to economize the consumption of water, which is obtained from the town supply, return pipes are laid to conduct the exhaust water from all the machines back again into a well in the engine house, from which the pumps draw their supply; and thus the same water is used over and over again. The steam engine for supplying the accumulators is situated on the quay level at A, with its boilers at B; it is a horizontal high-pressure engine with two steam cylinders, and the plungers of the double-acting force pump are attached directly to the piston rod. The engine is made in duplicate in all its parts, to admit of either side being worked separately in case of need. Double-acting lift pumps are provided for raising the supply and the return water from the storage well into a settling tank above the level of the engine, from which the forcing pumps draw their water. The engine is capable of forcing 209,350 cubic feet of water per minute against the accumulator pressure of 700 lbs. per square inch.

A number of experiments were made for the purpose of ascertaining the best means of conveying the grain horizontally from one part of the warehouses to another. The common method by means of revolving screws was first tried, the experiments being conducted at a brewery fitted up with this class of machinery. The screw employed was 12 inches diameter and 4 inches pitch, made in lengths of about 12 feet from bearing to bearing; the space between the screw and the fixed casing in which it revolved was ¼ inch. At sixty revolutions per minute, which was found to be the maximum effective speed, this screw discharged the grain at the rate of 6¾ tons per hour, and required a power of 0·04 horse-power for every foot run. The sectional area of the body of grain propelled was 49 per cent. of the whole transverse area of the screw. At a higher velocity than sixty revolutions the grain was simply carried round, and not propelled forwards at all. With a screw, afterwards tried, of 12 inches diameter and 12 inches pitch, driven at seventy revolutions per minute—the most effective speed—34 tons of grain per hour were discharged, and the power required to drive the screw was 0·125 horse-power per foot run, or 37 per cent. less than in the case of the previous screw for the same delivery of grain. The sectional area of the grain in motion was 72 per cent. of the whole area of the screw. The saving in power in this case

was owing to a better construction of parts, as well as the quick pitch. The effect upon the grain itself was very marked: with the first screw it was propelled without any appreciable agitation, but with the quick-pitched screw it was rubbed and polished, and thereby improved in marketable value.

In order to overcome the objections experienced with this screw, and to improve still further if possible the conditioning of the grain, trials were made with screws contained in revolving casings. A preliminary experiment was made with a 6-inch screw, 6 feet long, with 2 inches pitch and a depth of blade of 2½ inches; a portion of the casing was perforated so as to act as a screen, which it did effectually. A second trial was then made with a 30-inch screw, calculated upon the result of the preliminary screw to discharge at the rate of 50 tons per hour. The length of this screw was 18 feet, and its pitch 12 inches, or ⅖ths of the diameter. The body of the screw was properly balanced, and revolved upon finely adjusted rollers, carried in cast-iron frames. A third experiment was made with a screw 12 inches in diameter and 12 inches pitch, only with the view of ascertaining the effect of the quicker pitch. The results of these trials were as follows:—

The 6-inch Screw	discharged per minute, at	60	revolutions,	0·47	cubic foot of wheat.
Do.	do.	80	,,	0·60	,,
Do.	do.	100	,,	0·50	,,
Do.	do.	140	,,	0·00	(no delivery).

Showing that, as the grain in this class of screw is propelled forwards by gravity, centrifugal force comes into action at high speeds, and stops the discharge. With the 30-inch screw a speed of thirty-six revolutions per minute was found to be the most effective. At this speed the grain was carried up on the rising side of the screw about 5 inches above the centre of the casing, and the discharge was 63½ cubic feet, or about 80 tons of wheat per hour, which was a much higher duty than had been calculated upon. The power required was 0·40 horse-power per foot run; and the sectional area of the body of grain was 36 per cent. of the whole area of the casing. The 12-inch screw, driven at the same speed of thirty-six revolutions per minute, gave 10 tons of wheat per hour, with a sectional area of only 17 per cent. The pitch of ⅖ths of the diameter proved the most effective of those tried. The use of these screws with revolving casings was highly advantageous to the grain, which became well rubbed and polished; and they also obviated

the principal objection experienced with the screws in fixed casing, which harboured dirt and caused the grain to be injured by the action of the screw blades revolving within it. The great power necessary to drive the screw with revolving casing was found, however, an insuperable objection to its adoption upon a large scale.

The long distances over which grain had to be conveyed horizontally in the warehouses, amounting collectively to 7000 feet, or about 1 1/3 mile, and the power required for conveying it even with the best form of screw, rendered it expedient to seek some other mode of transport requiring less power; and recourse was therefore had to endless travelling bands. After a few preliminary trials with small canvas bands, experiments were made with a flat band 12 inches broad, constructed of canvas and india rubber. In working out this arrangement the first point to ascertain was the highest speed that could safely be used with different kinds of grain. A speed of 8 feet per minute was found to be the maximum for oats and other light grain; and at this speed even bran and flour can be conveyed without any portion being blown off by the resistance of the air in the passage of the band. A speed of about 9 feet per second can be reached with heavy clean grain, and a still higher speed with peas; chaff is blown off at a speed of about 9 feet per second. The quantity of grain discharged by the 12-inch band, travelling at a speed of 8 feet per second, was about 35 tons per hour. Further trials were then made with a band 18 inches broad, formed of two plies of stout canvas, covered with vulcanized india rubber; and this pattern was subsequently adopted for permanent use. The band was made continuous, extending over a distance of 37 feet, and was supported on plain cylindrical carrying rollers, fixed at intervals of 6 feet apart. The rollers were made of wood, with wrought-iron spindles revolving in bearings of white metal, and lubricated with hard grease. The band was driven by shafting, and provided with a self-tightening apparatus similar in construction to that finally adopted in the warehouses, consisting of a heavy tightening pulley suspended upon the band, and sliding vertically between guides. The maximum quantity of heavy grain conveyed by an 18-inch band is at the rate of about 70 tons per hour, and the power required to drive the band when working at this rate is equal to about 0·014 horse-power ($\frac{1}{70}$th) per foot run. The grain has no tendency to fall off the band, and indeed it is surprising to see separate grains at the edge of the band remain

steadily in position whilst passing over the carrying rollers at the highest rate of speed. Comparing the amount of power required to convey a stream of grain at the rate of 50 tons per hour through a distance of 100 feet, by means of the common screw in stationary casing, the tubular screw with revolving casing, and the travelling band 18 inches wide, the following are the results:—

With the common screw	18·38	horse-power.
,, tubular screw	25·00	,,
,, 18-inch travelling band	1·02	,,

This shows the great superiority of the band over the screws in economy of power.

For the purpose of passing the grain off at any point on either side of the main travelling bands, several contrivances with air-blast and brushes driven from the band itself were tried, but with indifferent success; both methods were objectionable on account of raising dust, and the friction of the brushes proved injurious to the band in course of time. The idea then occurred of diverting the stream of grain by means of an upward deflection of the carrying band, which would throw it clear from the band into the air for a short distance, and in falling it would be caught and led off by a spout to either side as required. This plan proved successful, and has been extensively adopted in connection with the use of the endless travelling bands for carrying grain. The throwing-off apparatus is shown in Fig. 212. It consists of a couple of wrought-iron rollers B B, centred in gun-metal bearings in a rocking frame C, which is hung in a movable carriage D running upon the timbers E of the wooden framing that supports the travelling band I I. The carriage is moved to any position along the length of the band where the grain is required to be discharged, and is then secured by the wedges F F and the clamping screw G. The rocking frame C is rotated in either direction by means of the screw and worm wheel H, so as to bring the pair of rollers B B into action at the proper position for throwing the grain off in the direction in which the band I is running; and the rollers are turned back into the horizontal position so as to be clear of the band when the carriage D is required to be moved to another position. A curved spout K is attached to the carriage D for catching the stream of grain in its fall, and leading it off on either side of the band I. No difficulty is experienced in keeping the grain on the band; but it is found necessary to let it fall upon the band from a feeding hopper through

a spout rather less than half its breadth, and set at an inclination

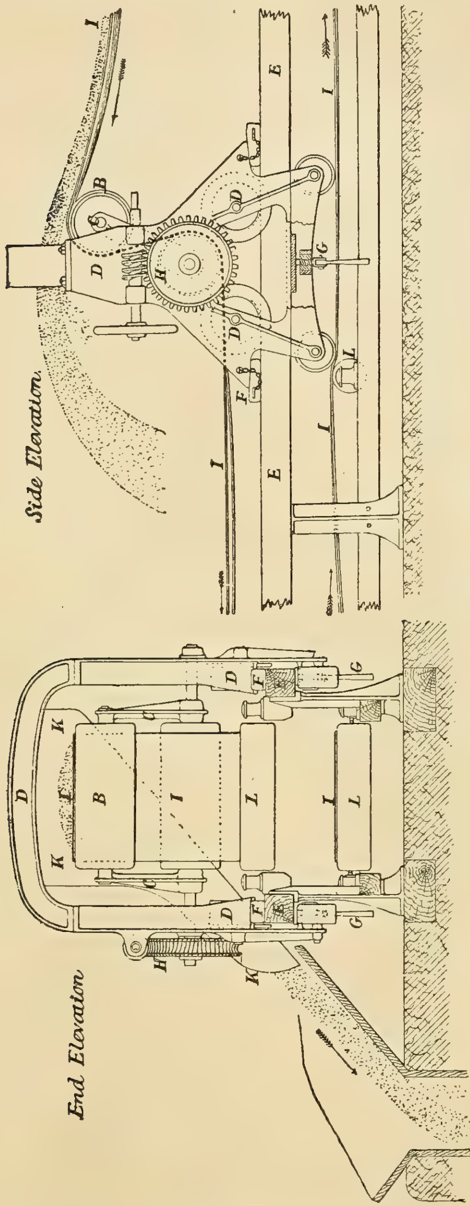


Fig. 212.—Throwing-off Apparatus.

B, Rollers. C, Rocking frame. D, Movable carriage. E E, Timbers. F F, Wedges. G G, Clamping screws. H, Worm wheel. I, Travelling band. K, Spout. L, Roller.

of 42½°, so as to give the falling grain a horizontal velocity nearly equal to that of the band. The fine dust and grit thrown off with

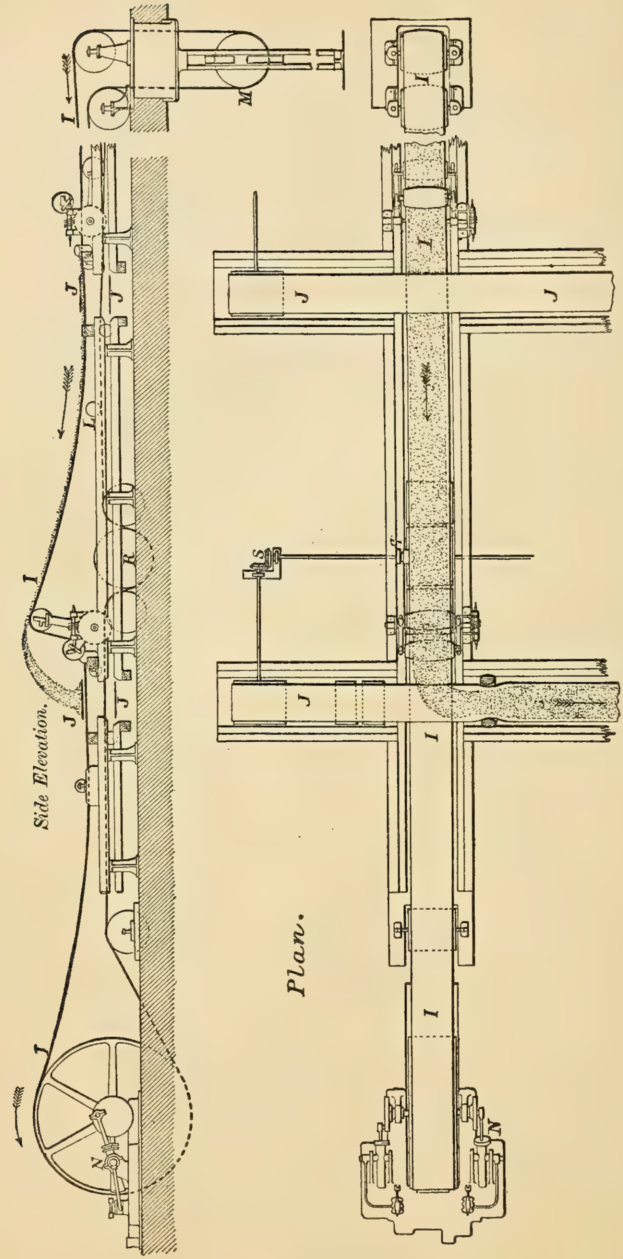


Fig. 213.—Travelling Band and Gear.

I, Band. J J, Cross bands. M, Tightening pulley. N, Hydraulic engine. R, Driving roller. S, Mitre wheel. T, Clutch.

the grain at this and other parts of the machinery require it to be

protected from injury at such places. As the flow of various kinds and conditions of grain through the spout from the hopper varies considerably, it is found desirable to place a pair of oblique side rollers at the point where the grain falls upon the band, in order to give it a slightly hollow form, and so prevent the grain from spreading. In passing heavy quantities of grain along the bands to great distances it has also been found expedient to apply at intervals pairs of these oblique side rollers, which are carried on movable frames that can be set at any required spot.

The cross bands J J (Fig. 213), for conveying the current of grain in a direction at right angles to the main bands, are driven from the lower or return half of the main band, which is passed half round a driving roller R, at each of the cross bands; and the motion is communicated from this roller to the cross bands through a pair of mitre wheels S, having a clutch T for throwing the driving shaft in and out of gear. The cross bands or other machinery, such as the centrifugal distributing fan, can also be driven by depressing the return half of the main band by a roller carried in a rocking frame so as to bring the band well into contact with a fixed roller situated underneath, which can then communicate the required motion for any purpose; and this simple mode of taking off power from the main bands has proved of service in many ways.

A revolving fan for spreading the grain over the floors of the warehouses, and for ventilating it and improving its condition, has been used with success. This fan is carried upon an upright shaft, driven from the main band by the same arrangement as that described for driving the cross bands. As the band is required to travel in opposite directions, the fan is made with straight radial vanes, to allow of its revolving in either direction. The grain is led by a spout on to the top of the fan, and to avoid the separation of heavy and light particles in the mass, and to spread it as evenly over the floor as possible, the body of the fan has a conical form, the alternate blades being made of a different length and shape, as shown in the enlarged view, Fig. 214. A hinged tongue is placed in the end of the delivery spout above the fan, and the discharge of the grain can be directed to any particular spot by turning this tongue round in the required position. The fan is placed 9½ feet above the floor, and at its usual speed of 250 revolutions per minute it deposits the grain in a circle of 45 feet diameter.

Five hydraulic cranes for discharging cargo are fixed in towers

specially constructed in the warehouses, as shown in Fig. 215. These cranes are fitted for raising grain in tubs containing 21 cwts. each, at a rate of 50 tons per hour under the most favourable conditions; and they are also employed for landing sacks, casks, and other merchandise on to the quay, or to any of the warehouse floors. The lifting chain has an extreme range of 130 feet, and the jib an extreme projection of 24 feet beyond the quay; a traversing motion of 7½ feet is given to the foot of the jib, but this is only required for the largest class of vessels. The motions are all effected by hydraulic power, under the control of one man stationed on a platform in the tower. The grain is filled into tubs in the hold of the vessel, and to find the best form for these tubs has been matter of some difficulty. The first form used was the ordinary tipping tub, which has by long experience been found to answer best for the discharge of coal, salt, gravel, &c. The next form tried required no tipping, but was fitted with a cone to deliver the grain through the bottom. The form that proved on the whole most satisfactory also requires no tipping, and is fitted with a butterfly valve in the bottom; when the tub is in position for emptying into the upper receiving hopper P, this valve is opened by a lever from the platform on which the man is stationed to work the crane. The time required by this tub for emptying itself depends on the kind and quality of the grain which it contains: with wheat in good and dry condition it is five seconds, with barley seven seconds, and with Indian corn from nine to ten seconds.

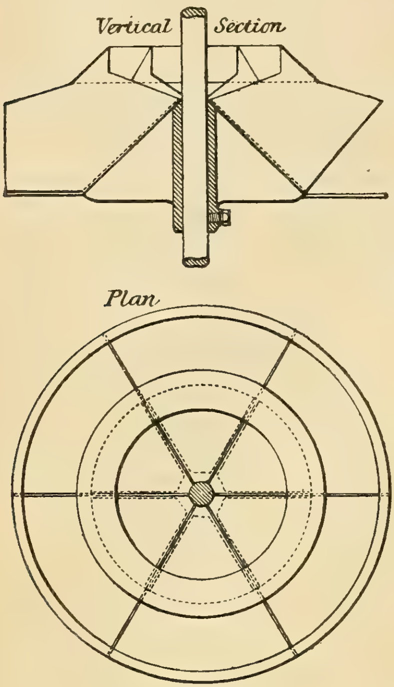


Fig. 214.—Distributing Fan.

The hopper P (Fig. 216), into which the grain lifted by the crane to the top of the warehouse is dropped from the tub, holds about 8 tons, and from this hopper the grain is diverted into two streams, and

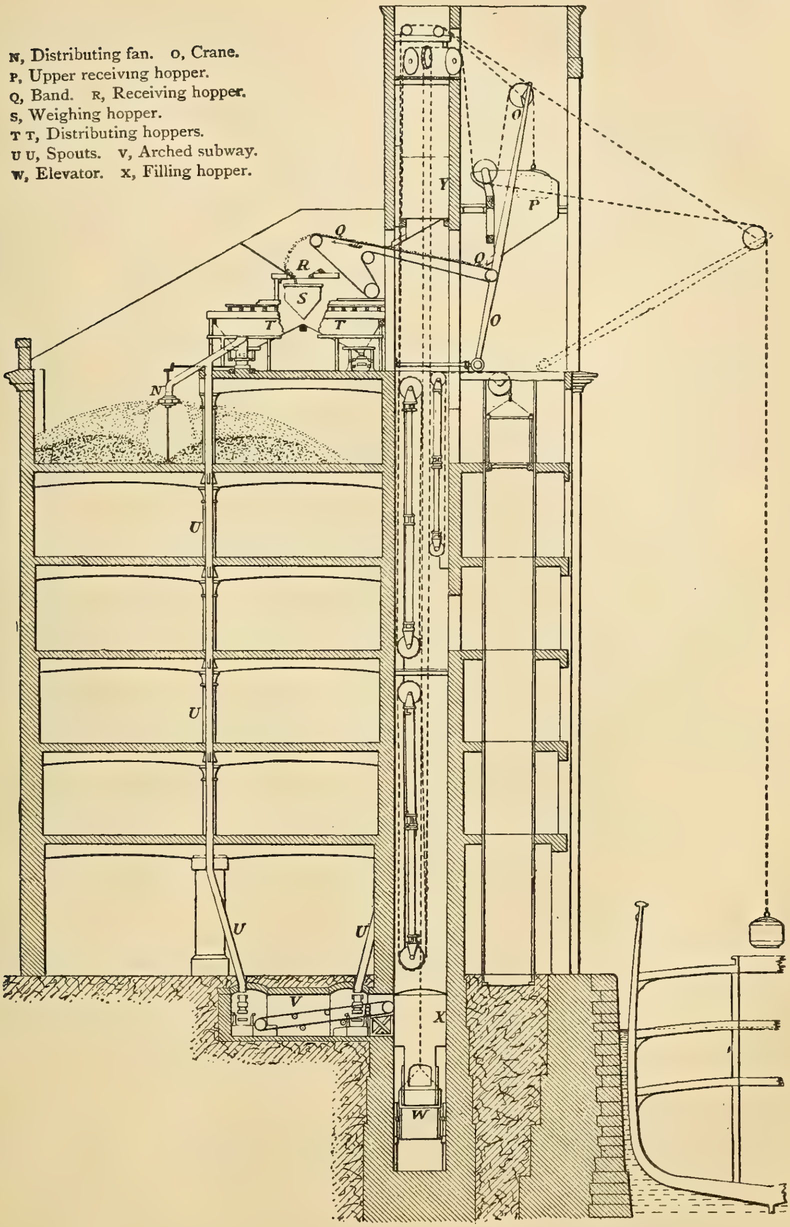


Fig. 215.—Transverse Section of Warehouse, showing Hoisting Gear, &c.

allowed to flow through the spouts fitted with regulators on to two 18-inch inclined bands Q, driven by one hydraulic engine. One of

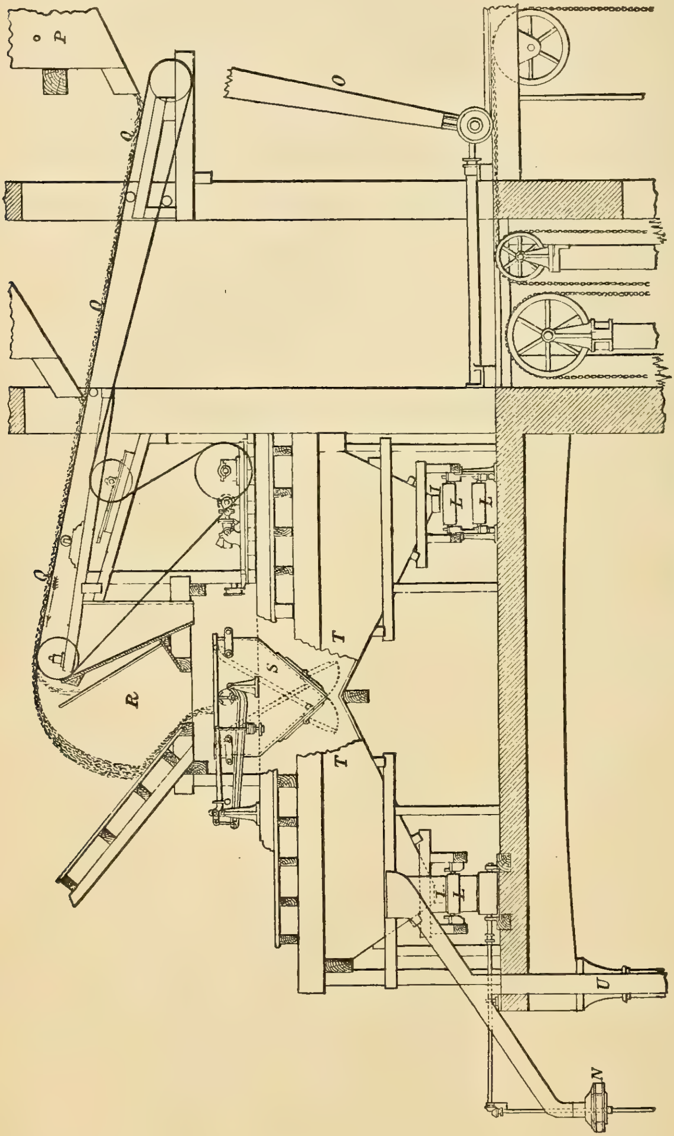


Fig. 216.—Machinery Floor.

I I Bands. L L, Rollers. O, Crane. P, Upper receiving hopper. Q, Band. R, Receiving hopper. S, Weighing hopper. T T, Distributing hoppers. N, Distributing fan. U, Spout.

these bands would be sufficient to carry the grain delivered by the crane, but two are employed to spread it out more, and to separate

the dust from it when required. This separation is effected by an inclined flap fixed in the inner receiving hopper R, into which the two bands Q convey the grain from the outer hopper P. From the hopper R the grain is allowed to drop through the valve into the 1-ton weighing hopper S; after which it is delivered, by a simple arrangement of doors in the bottom of the weighing hopper, to either side of the distributing hopper T, from whence it passes on to one or other of the 18-inch bands I I which traverse the entire length of the warehouses. The man stationed at the weighing machine S regulates the flow of grain from the several hoppers, and records the quantity passed.

Two main lines of 18-inch bands, made to run in either direction, are necessary for the convenient working of these warehouses. A vessel, for instance, lying at the west block of the warehouses may require her cargo deposited at either end of that block, or at any spot in either of the other two blocks; and at the same time another vessel lying at the east block opposite may have its cargo housed in the west block. Thus it often happens that two streams of grain are flowing in opposite directions, and that one or both of these is carried right round the warehouses. The bands in the east and west blocks are divided into two lengths, and the bands connecting these two blocks and passing through the north block are in one length. Each band is fitted with a separate tightening-up apparatus, seen in Fig. 213 at M; and is driven by a separate hydraulic engine N, of about 3 horse-power, having two cylinders, and fitted with reversing and regulating gear, which can be controlled from any point along the entire length of the band. At each point where the flow of grain has to be diverted from a main band to a cross band, a fixed throwing-off carriage is stationed. Two movable throwing-off carriages are provided on each main band, for casting the grain off the band into the wooden descending spouts, 8½ inches square, which convey it from the top of the warehouse to any floor in the building. There are fifty-six of these spouts U U, Fig. 215, passing from the upper machinery floor down to the lower 12-inch bands in the arched subway V V below the quay level; they are provided with sliding doors at the different floor levels, to admit of the grain being shovelled into waggons on the railway which traverses the centre of the block, or on to the lower 12-inch bands for conveying to the elevators. A number of other shoots at suitable intervals are built in the walls of the warehouses

fronting the dock at the levels of the several floors, and each is provided at the first floor with a delivery outlet, to which a movable spout is hooked on, for delivering grain from the warehouse into vessels. The arrangement of the lowering band machinery is a counterpart of the upper, but upon a smaller scale, and without the movable throwing-off carriages provided on the upper bands, which are not required for the lower. These lower bands are employed for the purpose of conveying grain from any of the descending spouts to any of the five elevators W, which are fixed in the crane towers. The grain conveyed along these 12-inch main bands is thrown upon the 18-inch cross bands, which deliver it into the hopper X, supplying the elevator W; one 18-inch cross band will carry the full quantity of grain conveyed by the two 12-inch bands, and the cross bands are arranged to receive their motion from either line of the main bands. Much of the grain discharged from the vessels in the dock is sorted upon the quay, and is then thrown by hand into the hopper X of the elevators.

The elevator for raising the grain from the bottom to the top of the warehouses is shown on a larger scale in Fig. 217. The wrought-iron bucket W, capable of containing about 21 cwts., is slung from the lifting chain by an arrangement of bars and levers, and provided with guiding rollers running between the upright timbers, so arranged that on reaching the top the bucket tips over, and discharges the grain into the hopper Y. This hopper delivers the grain upon the same inclined cross bands Q that convey it from the outer crane hopper P. The bottom hopper is made in two parts, the upper of which X, protected by a grating, receives the bulk of the grain, while the lower compartment Z contains only one charge at a time for the elevator bucket W, and is separated from the upper portion by a sliding valve. The descending speed of the bucket having been checked, as it approaches the bottom it strikes the arm of the tappet lever A, which closes the valve between the two compartments X and Z of the hopper; and continuing its descent still more slowly, the bucket strikes another tappet arm B, which disengages the iron flap C that covers the front of the lower compartment Z; this flap, falling forwards by the weight of the grain behind it, shoots the contents of the lower hopper Z into the bucket W. As soon as the bucket has received its charge the motion is reversed for lifting. Beginning to ascend at a moderate speed, the bucket closes the flap C of the lower hopper, which

is held up against it, as shown dotted, by means of spring

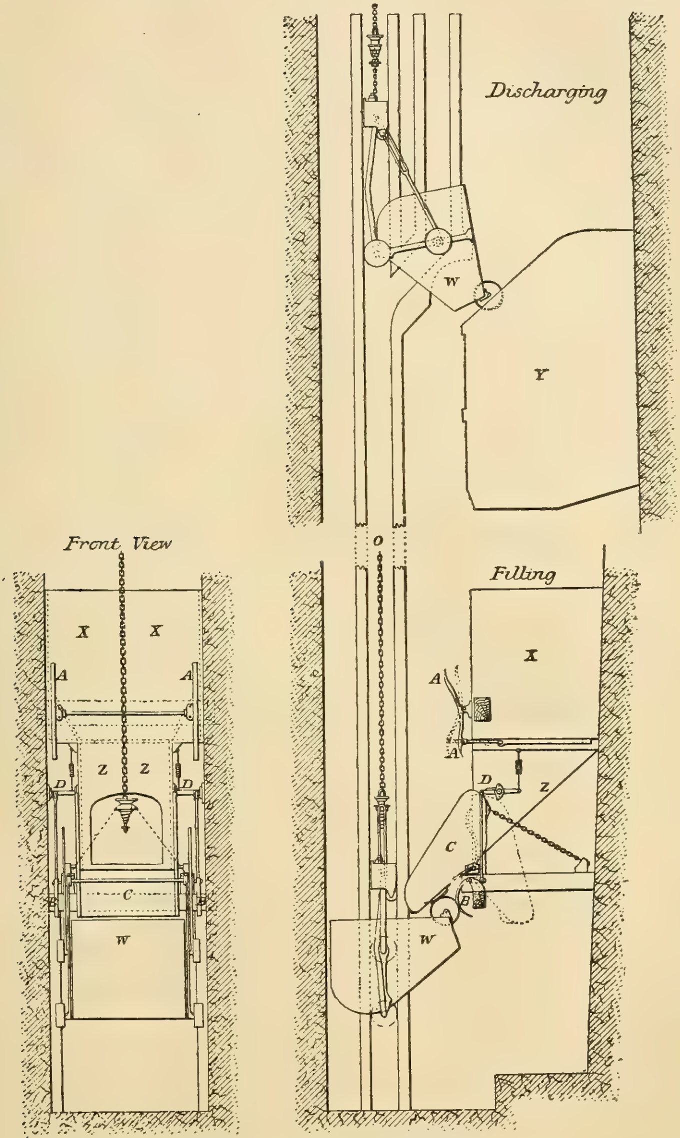


Fig. 217.—Elevator for Lifting Grain into Warehouse.

A, Tappet lever. B, Tappet arm. C, Flap. D D, Spring catches. O, Chain. W, Elevator. X, Filling hopper. Y, Receiving hopper. Z, Filling compartment.

catches D D; and the bucket then strikes the tappet lever A of the

hopper valve, and re-opens the communication between the two compartments X and Z. The speed is then accelerated until the bucket arrives near the receiving hopper Y, when it is again retarded before the grain is shot out. The motion of the bucket is regulated by self-acting gear. These bucket elevators are intended to raise the grain at the rate of 50 tons per hour, but they are capable of being worked at a higher speed. The chain O of the crane is employed for lifting the bucket of the elevator; but it has been found expedient, on account of the demands of the traffic, to make the elevators also independent of the cranes, and therefore separate hydraulic cylinders with their adjuncts have been supplied for working the former.

Trials have been made for lifting grain by means of dredging machines, and it has been found that with a dredger 30 feet long 50 per cent. of the applied power proved effective. Experiments have also been made for raising corn by air pressure or suction, and the results obtained are sufficient to prove that this system possesses certain advantages over the plan in use; but it is surrounded with difficulties and obstructions which must be removed before it can be employed with advantage upon a large scale.

Casks, bags, and other merchandise are raised or lowered either by hydraulic cradle hoists or by jiggers. There are twelve hydraulic hoists of the ordinary construction, each capable of lifting a load of 1 ton to the uppermost floor of the warehouses. They are found also serviceable in breaking out the cargoes from the fore and aft hatchways of a vessel lying with its centre hatch in line with the crane or elevator. For this purpose the lifting chain is disconnected from the cradle of the hoist, and led through a snatch block fastened to some part of the vessel. The twenty single-acting outside jiggers, originally constructed only for lowering loads by friction, have been supplied with auxiliary hydraulic power for lifting loads from 6 to 7 cwts. Twelve double-acting jiggers, for loads up to 10 cwts., have been added in the centre of the warehouses, for lifting or lowering goods to railway waggons; they are so constructed that they can be used singly or together, and for lifting or lowering. Both machines may be alternately lowering goods into waggons below from any of the floors of the warehouses, or by means of the water pressure they may both be raising goods from the waggons to any of the floors; or one side of the machine may be lowering whilst the other is hoisting goods from the hatchways of vessels to which the lifting chain has been led.

HYDRAULIC MACHINE TOOLS.

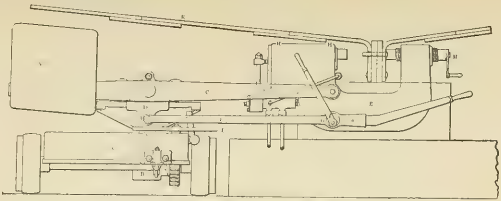


Fig. 4.—Machine for Rivetting Keels.

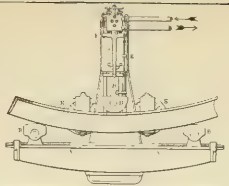


Fig. 5.—Angle-Iron or Beam Straightener or Bender.

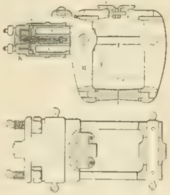


Fig. 1.—Portable Rivetter.

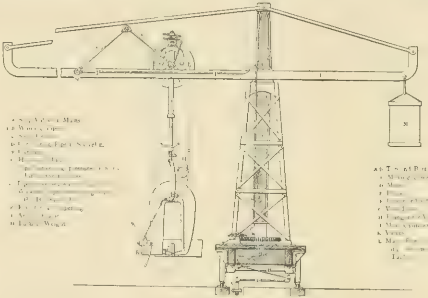


Fig. 2.—Travelling Crane for Rivetter.

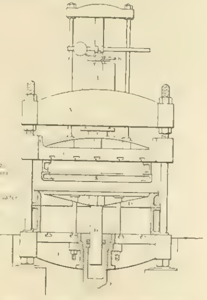


Fig. 3.—Hydraulic Press for Flanging Plates.

HYDRAULIC MACHINES FOR RIVETTING AND FLANGING PLATES, RIVETTING KEELS, AND ANGLE-IRON OR BEAM STRAIGHTENER OR BENDER.

DESIGNED BY MR. R. H. TWEDDELL

HYDRAULIC MACHINE TOOLS.

See Machine Tools and Hammers—Appendix.

The application of hydraulic pressure to single machine tools may be said to date from about the year 1847, when Mr. Fox used the Bramah press for the purpose of forging. Since then a variety of hydraulic tools have been introduced, amongst which may be mentioned those for forging and welding, rivetting boilers and ships' frames, fixing boiler tubes, for bridge and girder work, bending angle irons, flanging plates, shears for cutting chain cables, beam straighteners or benders, &c.

Fig. 1 in the Plate shows a portable rivetter, having the cylinder A between the fulcrum B and the rivetting dies C C.

In designing portable rivetters for ship and bridge rivetting some form of flexible pipe is necessary, to convey the water to the working parts; and copper pipes or india-rubber hose are used for this purpose. The cranes carrying the rivetters are either attached to fixed posts, or, as shown by fig. 2, the posts are movable on a trolly, and by means of the walking pipes B B, connected to the stop valve A and a swivel joint C, the whole apparatus may be moved at pleasure. By means of connections at D and E at the foot of the crane post, the pressure is conveyed by the pipe I I to swivel Q, where the walking pipes I′ I′ convey the water to the hydraulic lift G on the carriage F, and a copper pipe H conveys the pressure to the rivetter. Such a machine will put in over 2000 rivets per day.

Fig. 4 shows an arrangement designed for the rivetting of ships' keels, where the small depth of the rivet heads and their great size requires special arrangement. A post BB carrying a turntable revolves on the trolly A, a pair of levers C, attached to a carriage D, carry the rivetter E, which can be raised at pleasure to suit the work, and is kept vertical by means of a parallel motion F; the whole is counter-balanced by the weight N. The keels of the *City of Rome* and *Servia* were rivetted by such a machine, and the advantage of so powerful a method of closing up the rivets is evident when it is considered that the keels of such large vessels are made up of a number of plates and bars of great thickness. As a matter of experiment, as many as 24 plates, each ½ inch thick, have been closed up or rivetted apparently into a solid piece, showing what

work can be done by a suitable combination of pressure and percussive action.

Fig. 3 shows a machine for flanging plates. On the bottom casting B a matrix D is fitted, upon which the plate to be flanged is placed, and by means of the block E descending the plate is turned over upon its edges; to prevent buckling a cylinder F is fitted with a plunger H carrying a table G on its ram, by means of which the plates can be gripped between the table G and the block E.

Fig. 5 shows a machine for bending or straightening angle irons and beams. The piece to be bent rests upon the abutting blocks B B, which are adjustable by right- and left-handed screws A A, and by means of a tappet gear the supply of water and also the travel are regulated according to the work required, thus insuring exact repetition and accuracy in work.

A very extensive adoption of hydraulic power to machine work has been made at the French arsenal at Toulon, where amongst others two punching and shearing machines, and also angle-iron benders similar to fig. 5 are used, capable of exerting 100 tons of pressure. There is also a stationary rivetting machine exerting 40 tons pressure, and a number of portable rivetting machines for rivetting the cellular bottoms and decks of ships, at a distance of 1300 feet from the accumulator. The pressure used is 1500 lbs. per square inch. It appears that less steam power is required by this hydraulic arrangement than would otherwise be the case, and the author of the paper to which we are at present indebted says, "A moment's consideration will show that when gearing is used the prime mover must be equal to the maximum demand which can be made on it at any moment. The accumulator, however, affords a smaller engine the opportunity, when not otherwise fully engaged, of storing up by easy stages an amount of power equal to the greatest instantaneous demand likely to be made, and as long as the work required is not equal to the power of the pumps, this process of putting by power, as it were, is going on, consequently a much smaller prime mover will suffice, which means less boiler power and a more economic use of steam."[1]

[1] See a valuable paper and drawings in *Trans. Inst. Engineers and Shipbuilders in Scotland*, vol. xxiv., by Mr. R. H. Tweddell of London, who has been of late years highly successful in applying hydraulic pressure to tools on a complete scale.

MARINE ENGINES.

THE OSCILLATING ENGINE.

The *vibrating* or *oscillating engine* introduced by Maudslay in 1827, with its varied modern improvements, is very suitable for paddle-wheel steamers, the comparatively small space it requires fitting it admirably for this class of vessel. It is the most direct-acting kind of engine which we have; the piston rod is connected to the crank pin directly, thus saving height in the engines where that is a desideratum, and the weight is most satisfactorily placed, being neither too high nor too low in the ship. The many examples—from the small river boats on the Thames of 30 horse-power collectively, to large ocean steam ships such as the *Great Eastern*, the largest ship as yet constructed, with oscillating engines for the paddle wheels of 1000 nominal horse-power collectively—all bear testimony to the success of the oscillating type of engine. It may be regarded as the only example left of the many classes of engines that have been successfully applied to paddle-wheel ships; and from our being able to couple the crosshead of the piston rod directly on the crank pin, and keep the weight of the machinery below the deck, the oscillating engine is likely to remain long in use for shallow river boats propelled by paddle wheels, for undoubtedly this method of propulsion possesses many advantages over the screw propeller for vessels of light draught, especially when they are built to attain great speed.

The peculiar motion of these engines—the *cylinders* vibrating on central hollow trunnions—requires the parts to be nicely balanced; and as the piston rod takes the side strain and the strains imparted by the action of the steam on the piston, it requires to be made of greater diameter than for ordinary engines, where it is only subjected to tension and compressive stress.

The *trunnions* should be so placed that the preponderance of the weight of the cylinder is towards the bottom, by which means the

strain on the piston rod is not so much felt, and when the crossheads are uncoupled from the crank pins the cylinders are not so liable to tilt. This will be found a great convenience when undergoing repairs at sea. The larboard and starboard trunnions are for the steam, which passes through a belt cast along with the cylinder into the valve casing. The faces for the valves are generally of the three-ported type, two ports are for the steam and a central one for the exhaust. The two central trunnions are for the exhaust steam, which passes into the belt around the cylinder, and then into the

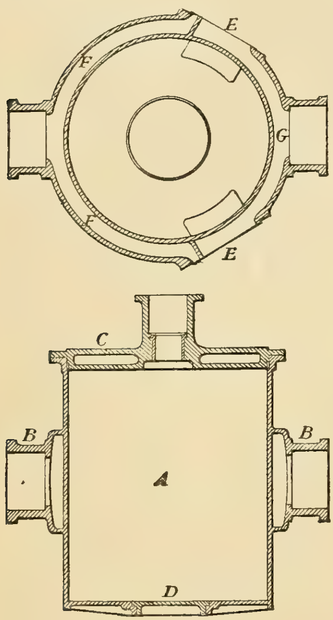


Fig. 220.—Cylinder.

A, Cylinder. B B, Trunnions. C, Cylinder cover. D, Bottom cover. E E, Valve faces. F F, Steam passages. G, Exhaust passage.

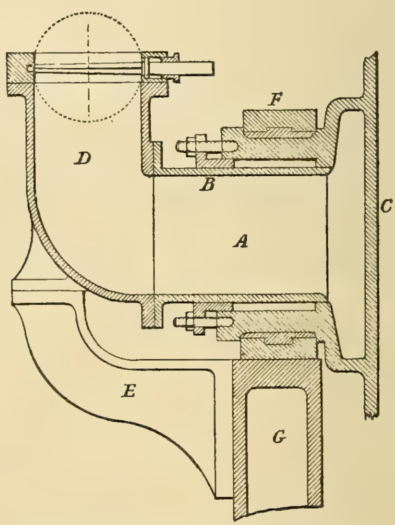


Fig. 221.—Trunnion Pipe and Stuffing Box.

A, Trunnion pipe. B, Gland for stuffing box. C, Cylinder. D, Throttle-valve pipe. E, Bracket for supporting do. F, Pillow block. G, Frame.

condenser through the hollow trunnions; thus one half of the belt allows the steam from the boiler to pass into the valve casing, and the other half acts as a passage to the condenser, the division being formed by feathers or bars cast in the cylinder.

The *trunnion pipes* for the steam and exhaust are fitted with glands and packing spaces formed in each trunnion; the former are bolted to the branch pipes, which are supported by brackets bolted to the bottom frames, and the latter are bolted to the condenser casting,

and packed with hemp or other packing, similar to the piston-rod packing. The branch pipes are bent upwards, and on the top flanges are placed the throttle and expansion valves; thus an immovable pipe, in communication with the valve casing which vibrates along with the cylinder, is made perfectly steam-tight.

The *steam valves* are generally formed in duplicate, one being placed on each side of the cylinder; while, for long-stroked engines of this class, four valves have been introduced. In the former case the horizontal line of location, or centre line of the exhaust port, is on the centre line of the trunnions; in the latter, the valves are placed above and below the trunnion centre line, with the object of reducing the length of the steam ports, and thereby saving steam at each stroke of the engine, and consequently fuel. The object of placing the valves on each side of the cylinder is to balance it, each valve is also greatly reduced in size; but notwithstanding that the valve gearing is more complicated, double valves are generally adopted, as they secure a neater and more equally balanced cylinder. One valve may be used for very small power, and a weighted lever placed on the opposite side of the cylinder to balance it.

The *stuffing box* and *gland for the piston rod* of the oscillating engine is made very deep, giving a large bearing surface to take the side strain caused by the vibration of the cylinder; and in cases where the proportions allow of great space between the end of the crosshead and the top of the gland bolts, the part cast along with the cylinder cover can be made of any convenient length, with a brass bush inserted at the bottom, and the necessary bushes and glands at the top of the long neck piece, as in ordinary arrangements. Care must be taken to have a small amount of clearance all round the piston rod below the stuffing box, or to insert a very deep bush.

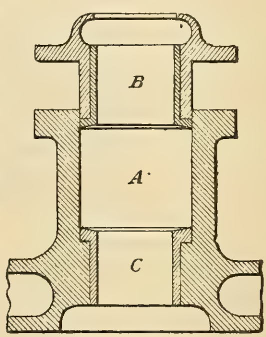


Fig. 222. — Cylinder-cover Stuffing Box.
A, Stuffing box. B, Gland. C, Bottom bush.

The *condenser* in the ordinary injection system is placed between the cylinders, and in the surface system it is placed on the centre line of the ship, behind or before the cylinders as the case may be. The latter is not so compact an arrangement as the former, but it is necessary, as the space taken up by the surface system will not allow the condenser to be placed as with plain injection.

The *air pumps* for the injection system are either single or in duplicate, lying at an angle; when one pump is used it is

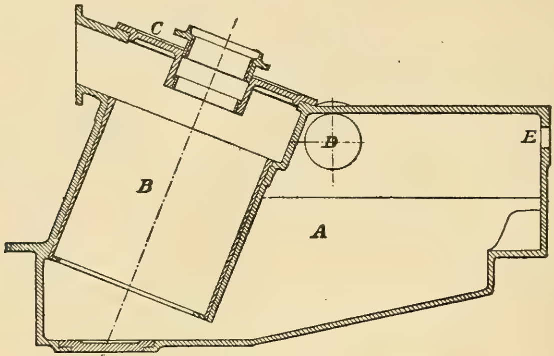


Fig. 223.—Single Air Pump and Condenser.
A, Condenser. B, Air pump. C, Air-pump cover. D, Exhaust passage. E, Hole for injection valves.

generally placed forward in connection with the cylinders; when two are adopted, one is forward and the other aft of the centre line of the engine. They are worked directly from the intermediate

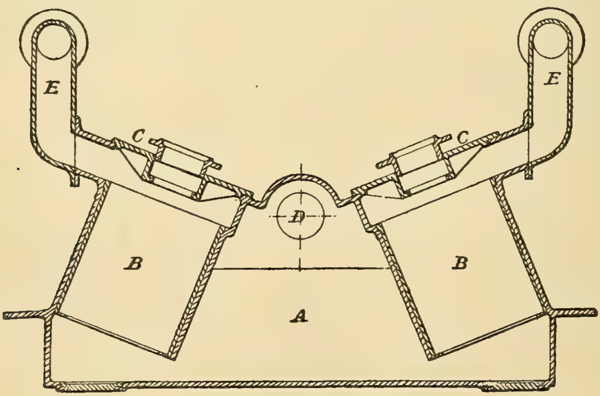


Fig. 224.—Double Air Pump and Condenser.
A, Condenser. B B, Air pumps. C C, Air-pump covers. D, Exhaust passage. E E, Hot wells.

crank shaft, with one rod for the single pump and two rods on the same crank for the double arrangement. The rods have suitable crossheads for taking the crank pin, and their bottom ends are fitted with pins and joints, secured with large brass nuts through the air-pump buckets, with trunks fitted to them, which serve as guides, instead of crossheads and guide bars. The bottom part of

the connecting rod has a hole bored up through it, and is fitted with an internal steel rod which can adjust the bottom brasses with a screwed key and jib.

In some examples the air pumps have been placed vertically, one on each side of the centre line of the engines, having a single connecting rod from the crank pin, taking a vibrating beam placed above the pumps, to which the buckets are connected at the ends by rods and guiding trunks, the point of connection for the main rod being placed within the centre line of the forward pump, whereby less throw is required for the crank on the intermediate shaft. This plan, however, is not so good as working the pump directly from the shaft, the connecting rod taking a crosshead on the air-pump rod, and which is guided with cast-iron guide frames bolted to the top of the air-pump cover.

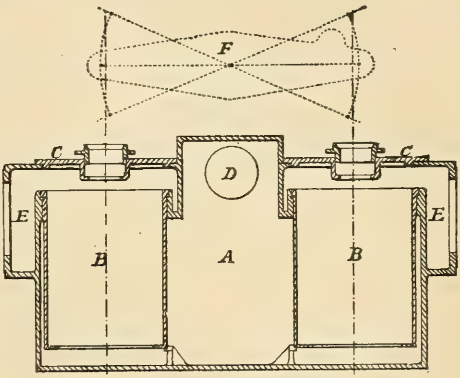


Fig. 225.—Double Air Pump and Condenser, arranged vertically.

A, Condenser. B B, Air pumps. C C, Covers for do. D Exhaust passage. E E, Hot wells. F, Rocking beam.

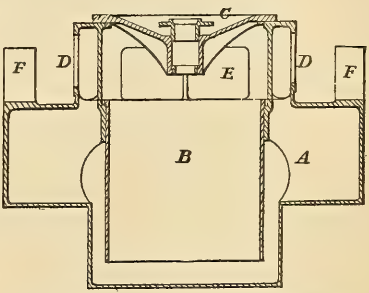


Fig. 226.—Single Air Pump and Condenser, arranged vertically.

A, Condenser. B, Air pump. C, Air-pump cover. D D, Exhaust passages. E, Discharge passage. F F, Pillow blocks.

The *air-pump bucket head* and *foot valves* (Fig. 227) are fitted with round discs of india rubber, working on suitable gratings cast on the bucket and valve seats, with the necessary guards to prevent or limit the lift of the discs. These valves are introduced to obviate the disagreeable knocking action felt in all pumps with metallic valves when working at great speed. Instead of one large disc of india rubber, several smaller ones have been fitted to the air-pump bucket head and foot valve, but for slow-speed engines one disc is quite sufficient. In all pump arrangements doors should be provided to inspect the valves, without requiring to draw the air-pump bucket; in this respect it is

more convenient to use smaller discs for the foot and head valves, the latter being placed above the bucket, at the bottom of the hot well, which is also fitted with a door to admit of occasional inspection.

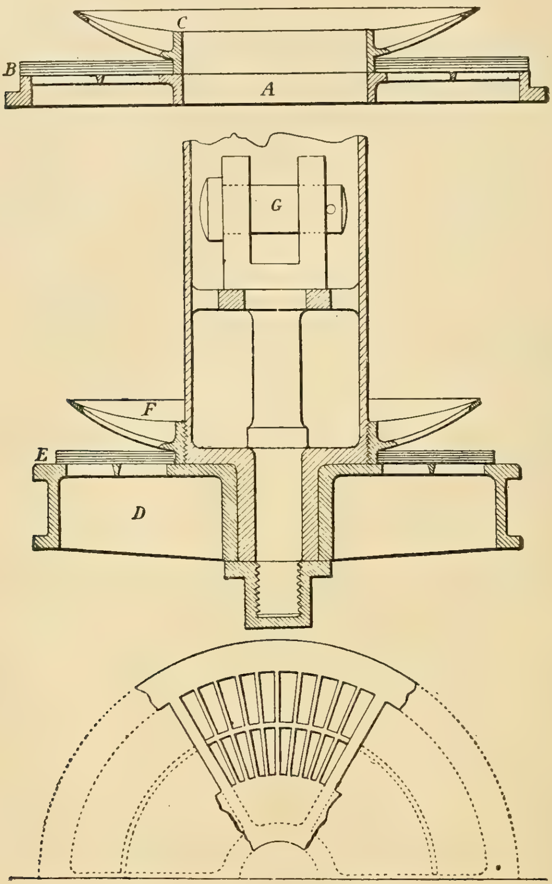


Fig. 227.—Bucket and Head Valve.

A, Head-valve seat. B, Disc of india rubber. C, Guard. D, Bucket. E, Disc of india rubber. F, Guard. G, Joint and pin for rod.

Cranked shaft.—As the intermediate cranked shaft in some engines, more especially those of large power, has caused great trouble, plain shafts have been substituted, and the air pumps worked by means of eccentrics. A single eccentric may be adopted for a small diameter of pump; but when the pump is large it is preferable to have two, with rods connected to a crosshead, with a single central rod for

taking the joint at the bottom of the trunk. In this way ample bearing surface is obtained, and the shaft is not so liable to be fractured as when the strain is received on the middle. The eccentrics should also be placed as near the main bearings in the headstock or top frame for taking the shafting as can be conveniently done, as the strain on the intermediate shaft is thereby better distributed.

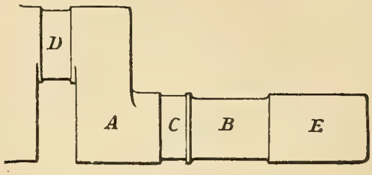


Fig. 228.—Cranked Shaft for Air Pump.
A, Cranked shaft. B, Main bearing. C, Bearing for eccentric. D, Crank pin for air-pump rod. E, Part for the piston-rod crank.

The *feed and bilge pumps* are sometimes worked off a double lever arm, fitted to the end of the trunnions; this plan necessitates a large diameter of pump, having a very short stroke, owing to the length of the vibrating arm. This arrangement does not make so

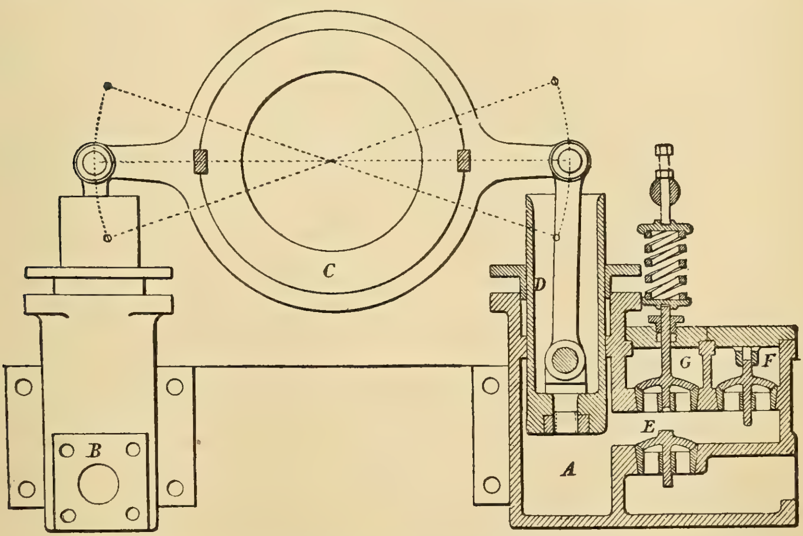


Fig. 229.—Feed and Bilge Pumps.
A, Feed pump. B, Bilge pump. C, Rocking arm and rods. D, Plunger and stuffing box. E, Suction valve. F, Discharge valve. G, Relief valve and spring.

effective a pump as when the stroke is increased, giving less diameter of plunger, which can be readily attained by placing the pumps on each side of the air pump, and connecting them to the crosshead fitted to the top of the trunk, when they have the same

length of stroke as the air pump. In this case the one acts as the feed pump, and the other, technically termed the "bilge pump," pumps out the water that accumulates in the hold of the ship. The feed-pump valves are formed either of metal or discs of india rubber; but as the bilge pump takes in many foreign substances, metallic valves of the flap type are preferable for it. Such valves answer very well for moderate speed, but should never be adopted for quick-going engines, as they would soon be knocked to pieces, and the noise they make at each stroke is far from agreeable.

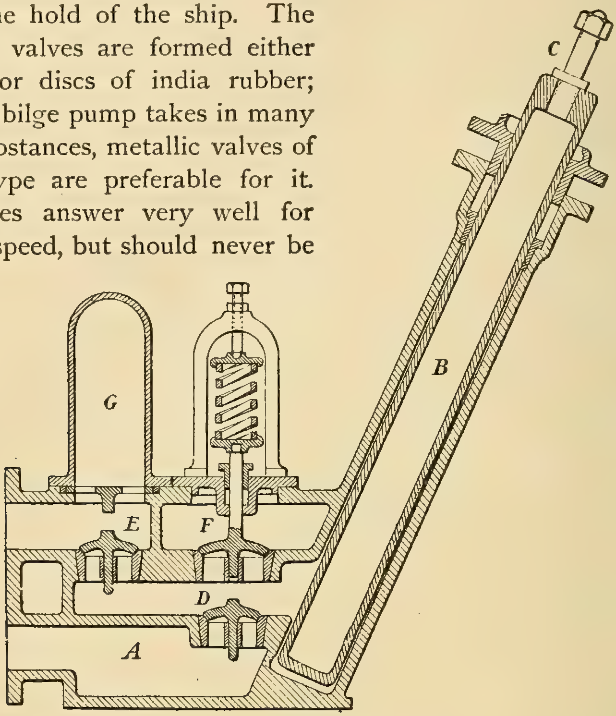


Fig. 230.—Feed Pump.

A, Feed pump. B, Ram for do. C, Pin for taking the air-pump crosshead at one end, and bilge pump at the other end. D, Suction valve. E, Discharge valve. F, Relief valve and spring. G, Air vessel.

The *bottom bed plate* for taking the trunnion blocks is a light casting of a T section; the pillow blocks for the larboard and starboard trunnions are sometimes cast on, and are fitted with brasses at the top and bottom, like any ordinary pillow block. Holes are left in the block piece for the main columns supporting the headstock to pass through, which are fastened by cotters secured through the casting. This arrangement makes a very stiff and strong bed plate.

The *trunnion blocks* are sometimes separate, bolted down on flanges on the bed plate; and the main columns are secured to

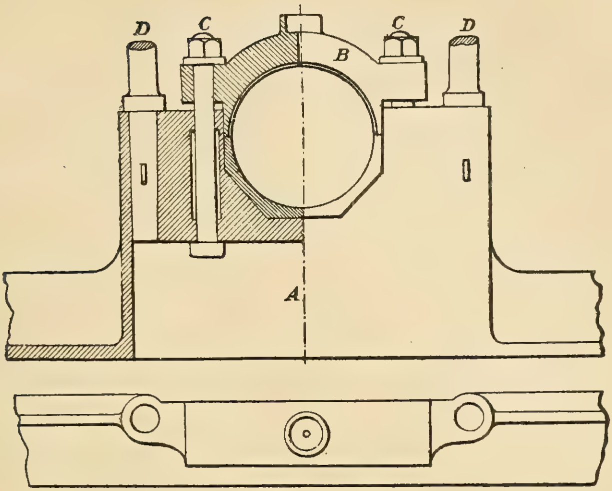


Fig. 231.—Trunnion Pillow Block cast on the Bed Plate.

A, Pillow block cast on frame. B, Cap for do. C C, Bolts for do. D D, Columns for supporting the headstock.

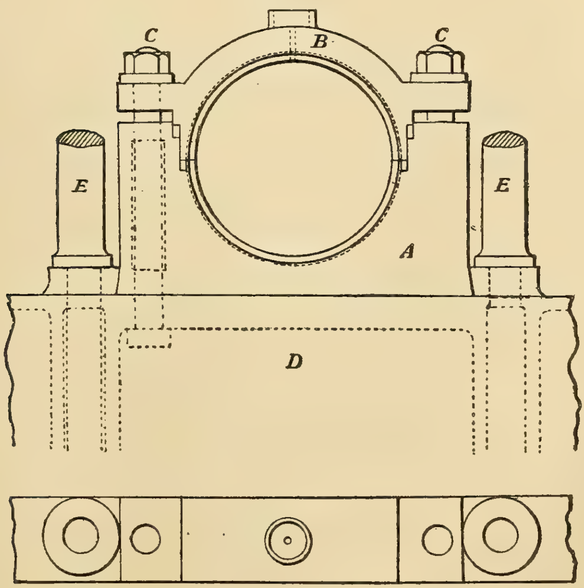


Fig. 232.—Trunnion Pillow Block separate.

A, Pillow block. B, Cap for do. C C, Bolts for do. D, Frame. E E, Columns for supporting the headstock.

strongly feathered bosses, and the necessary flanges are provided for bolting the bed plate to the condenser casting. The frame should be no larger than what is required for the oscillation of the cylinder; and the whole is bolted down on the top of wrought-iron bearers, securely rivetted to the vessel.

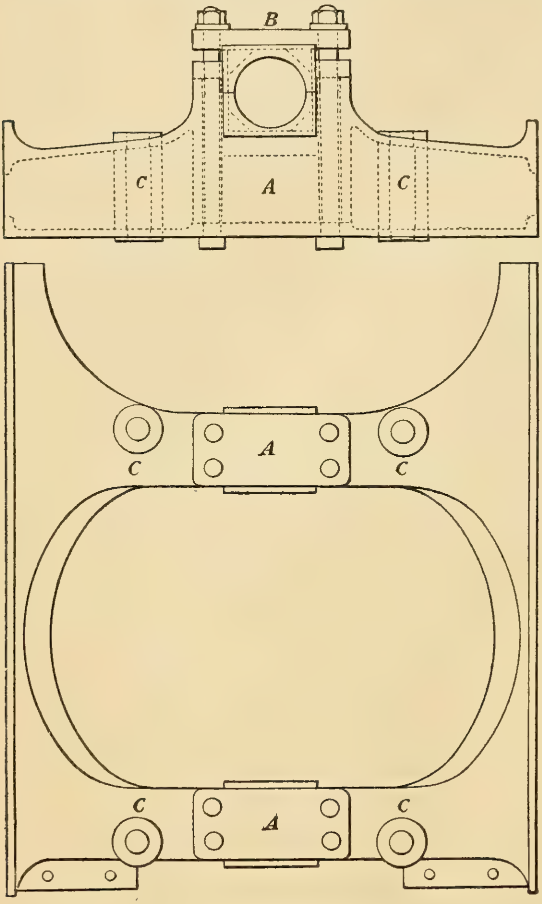


Fig. 233.—Headstock.

A A, Headstock pillow blocks. B, Cap for do. C C, Holes for columns.

The *headstock* for the crank shaft is of cast iron, but in some instances, where lightness is a desideratum, wrought iron has been used. For small engines the headstock casting is generally of an I section, but for large ones a box section is preferable. It is usually cast in two halves, bolted at the centre on the centre line of paddle-wheel ships, each half being fitted with two pillow blocks cast on, fitted with brasses at the top and bottom, and secured with caps of cast iron, having bolts passing down through the frame. Bosses for taking the main columns are cast along with the headstock. These columns are made of wrought iron, and are of sufficient strength to receive the thrust and weight that they are subjected to; and to give greater rigidity between the bed plate and the headstock, cross stays of cast-iron are introduced on the larboard and starboard columns. The headstock is placed between the engine beams which are made of plate iron of a box section; these

beams run from one side of the ship to the other, underneath the deck, and the lateral strain imparted from the headstock is taken on them, wedge pieces being introduced between them and the casting. As the strain is fore and aft, these engine beams should be made broad in the direction of the length of the vessel. The hatchway for the headstock cuts the deck in two at the middle of the vessel where strength is most required, and breaks the continuity of the deck stringers running fore and aft on the top of the deck beams to stiffen the vessel; it is therefore desirable to pass bolts of large diameter through the engine beams and headstock, by which the frame is firmly secured to the engine beams, and as the stringers are rivetted to these beams the longitudinal strength is maintained.

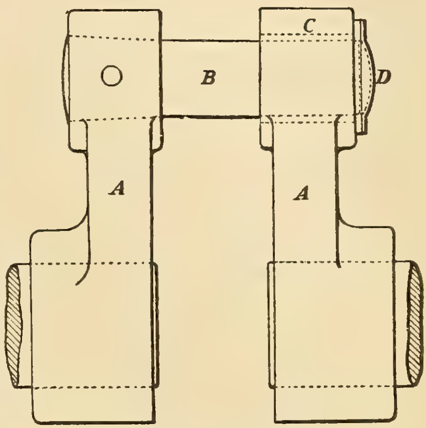


Fig. 234.—Main Cranks.

A A, Main cranks. B, Crank pin. C, Bush. D, End plate.

The *main cranks* are arranged in the usual manner, the crank pins being firmly secured in the inner ones; while the larboard and starboard cranks are fitted with brass bushes for the reception of the ends of the pins, in which they work quite loosely, thus preventing any undue stress on the main shaft in a heavy sea.

Piston ring and block.—We now come to notice the piston of the oscillating engine, which is fitted with a ring on the top, termed the junk ring. This is introduced to keep the packing ring in its place, and is bolted down with screw bolts, the brass nuts for which are let into recesses left in the body of the piston; the heads of the bolts are flush with the top of the junk ring, and are screwed down with a box key. The packing ring is generally in one piece; after it is turned on the rubbing face it is cut at one part and sprung into its place, the cut part being made steam-tight by a block piece of brass, with a wrought-iron guard secured to the spring ring at one end, and moving in a slot at the other end on a guide pin; the brass block is also secured to the ring at one end, and left loose at the other.

The use of this guard piece is to allow a wedge to be driven between it and the brass block, which contracts the spring ring; the piston is then placed in the cylinder, and when the wedge is removed the ring expands and fits the cylinder exactly. Curved steel springs are then inserted between the piston and the packing ring all round; thus with its own elasticity, and with the aid of these springs, the surfaces between the piston and cylinder are made quite steam-tight. All the parts should be carefully turned, and the surfaces between the junk ring and the piston scraped; no grinding material should be used to make this joint tight; in fact the use of emery for making steam joints, or for getting up journals, has long been discarded, as the small particles of grit are sometimes imbedded in the metal, and soon play havoc with rubbing surfaces.

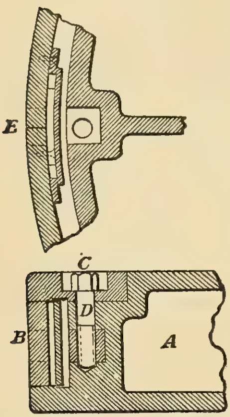


Fig. 235. — Piston Ring and Block Piece.

A, Piston. B, Packing ring. C, Junk ring. D, Bolt and recessed nut. E, Block and guard.

The *piston rod* is secured by a nut, sometimes placed at the top, in other cases at the bottom, square threads for which are cut on the rod. The nut is sometimes flush with the top of the piston, and is screwed into the recess by a spanner, fitted with a pin which takes

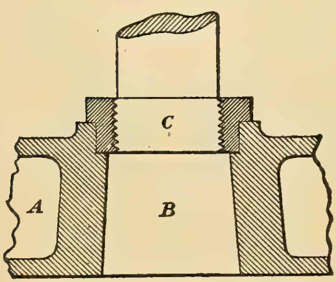


Fig. 236.—Top Nut for Piston Rod.

A, Piston. B, Cone on piston rod. C, Nut.

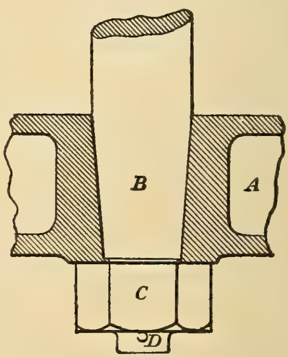


Fig. 237.—Bottom Nut for Piston Rod.

A, Piston. B, Cone. C, Nut. D, Pin.

the holes drilled in the top surface of the nut; a better plan, however, is to recess the nut partly, leaving sufficient projection so that it can be tightened up with an ordinary key. Of course the end of

the piston rod must be turned with a taper, to secure a perfect fit between the piston and rod. When the nut is placed at the bottom of the piston it is screwed up against the face ring, and is further secured by a cotter passing through the rod; this plan is generally adopted when the crosshead for the crank pin forms part of the rod. Some makers leave a collar for bearing on the top of the piston; and with a solid piston rod and crosshead the glands require to be cut. The collar, however, may be dispensed with, as a plain cone is quite sufficient. Recesses must be left in the cover and the bottom of the cylinders for the securing nut to pass into.

The *crossheads for the piston rod* are of various forms. Some are forged along with the rod, and slotted out for the reception of

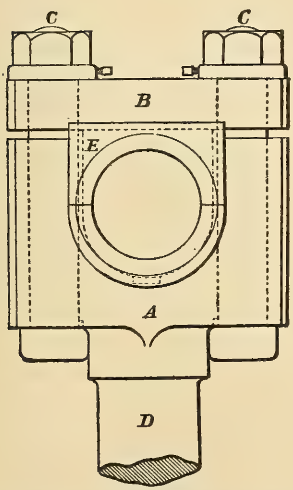


Fig. 238.—Piston Rod and Crosshead forged on.
A, Crosshead. B, Cap. C C, Bolts. D, Piston rod. E, Brasses.

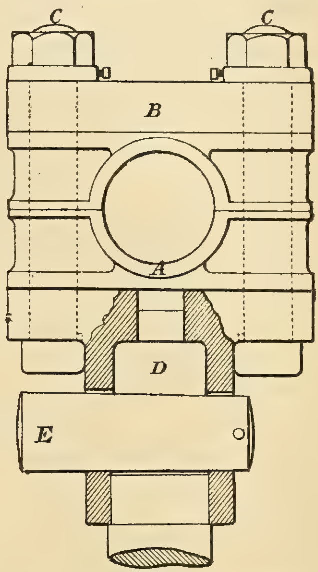


Fig. 239.—Piston Rod and Socket for Crosshead.
A, Crosshead of brass. B, Cap. C C, Bolts. D, Socket piece. E, Cotter.

brasses, which are secured by means of caps, held down with bolts passing through the crosshead; others are forged all in one piece, and are bored out for the reception of the rod, which is held in position by a cotter; others again have a T piece left on the rod, or a T bottom piece cottered to the rod, having the brasses cast to form the middle part of the crosshead, on the top of which is placed

the cap with bolts for screwing up the brasses. An oil chamber should be forged on the cap and then bored out, or a separate oil cup fitted with a siphon wick, for lubricating the crank pin.

The *air-pump rod crosshead* is similarly constructed, with a T piece formed on the rod, having brasses and cap with bolts passing through. The bottom part of the air-pump rod is generally left

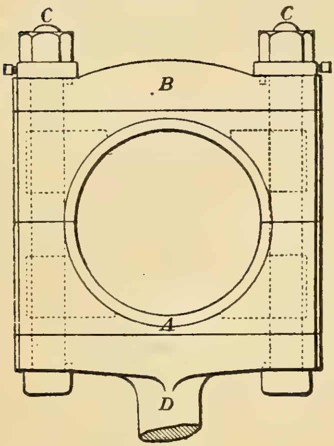


Fig. 240.—Air-pump Rod Crosshead.

A, Crosshead of brass. B, Cap. C C, Bolts and nuts. D, Rod.

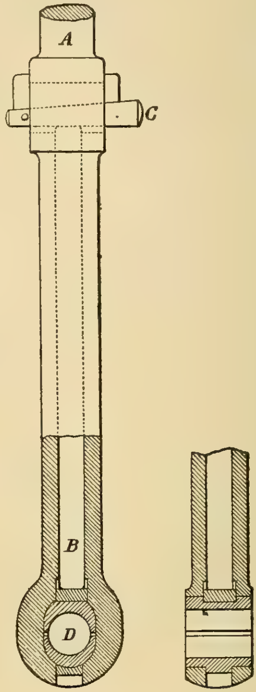


Fig. 241.—Air-pump Rod, bottom end.

A, Rod. B, Inside rod. C, Jib and cotter. D, Bush.

hollow, and is fitted with a steel bar inside, so as to be able to adjust the wear of the brasses; this plan is of course only adopted when the bottom of the rod is attached to the pin on the crosshead placed in a hollow trunk.

The *injection valve* generally adopted is the simple cone plug (Fig. 242), cast hollow and fitted with a stuffing box at the top, with a spindle carried up and supported by a round pillar, on the top of which is fitted an index; a handle is fitted to the spindle for actuating the plug, which has passages in connection with pipes from the sea for admitting water into the condenser. Sometimes flat sluices and gridiron valves are adopted, worked by levers connected to the valve spindles; others prefer disc valves having spindles through

the centre bosses left in the valve seatings, and lifted by separate screwed spindles with turn wheels and handles; and some small valves of this type are lifted by levers, the short end of the lever working in a slot crosshead screwed on the vertical spindle. The pipe placed inside of the condenser, in connection with the injection valve, should be perforated with a number of round holes or slits, so placed that the water is distributed or showered over a large surface. Some engineers have adopted distributing plates, perforated with round holes, so that the water falls into the condenser as in an ordinary shower bath. We prefer, however, the perforated copper pipe, which should taper to a smaller diameter at the end furthest from the valve. By this means the water is more equally distributed; for were the pipe to be made of equal area throughout the pressure would decrease, owing to the water escaping through the perforations, but when the pipe is contracted from the valve to the end which is filled up then the pressure is maintained more equally all along its length.

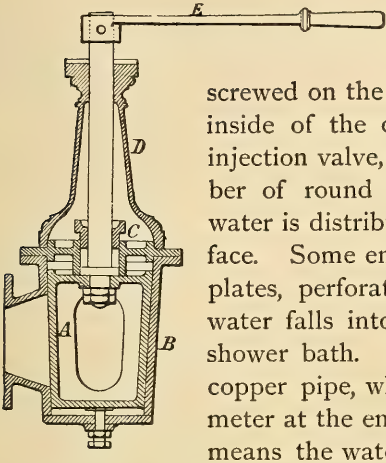


Fig. 242. — Injection Plug Tap.
A, Plug. B, Chest. C, Gland and stuffing box. D, Standard. E, Handle.

The *Kingston valve* (Fig. 243) is fitted to the side of the ship, with a cast-iron piece between the iron plates and the brass, to prevent corrosion from the oxidation caused by placing brass in contact with wrought iron. These valves are fitted to the vessel before it is launched; they consist of cone valves lifted by means of spindles, and are held in position by cotters passing through the spindles and bearing upon columns fixed to the covers; the spindles pass through these covers, and are made tight by stuffing boxes and glands. A gridiron is fitted at the bottom of the case or pipe containing the valve, to prevent extraneous matter entering the condenser. The use of the Kingston valve is to shut off the sea water in the event of any of the pipes which supply the engines getting damaged, in which case, if some contrivance were not adopted, the sea water would rush in and fill the engine or boiler room. A plug valve is also fitted to the Kingston valve, so as to shut off the sea water effectually.

The *blow-through valve* (Fig. 244) is fitted to the steam pipe, or

in communication with it and the condenser, so that steam from the boiler may be blown through the condenser and also into the

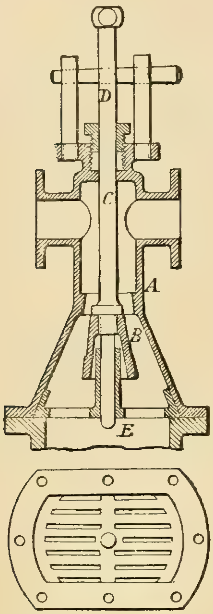


Fig. 243.—Kingston Valve.

A, Valve chest. B, Valve. C, Spindle. D, Cotter. E, Branch piece on ship's bottom.

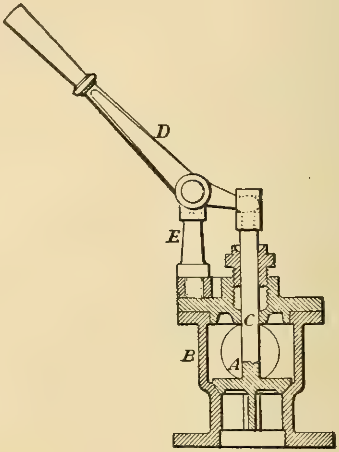


Fig. 244.—Blow-through Valve.

A, Valve. B, Chest. C, Lifting spindle. D, Handle. E, Stud.

cylinder, warming these parts and expelling the air; thus by turning on the injection a vacuum is formed in the condenser, before the steam from the valve casing is admitted into the cylinder. This valve is a spindle one, opened with a lever handle, and is held down by the steam pressure on the top side.

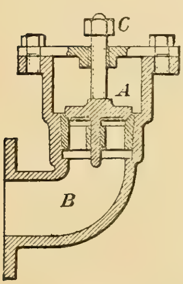


Fig. 245.—Snifting Valve.

A, Valve. B, Chest. C, Set screw.

The *snifting valve* is fitted to the lowest part of the condenser; by it all the air in the condenser escapes in the process of blowing through. It is a plain spindle valve, fitted in a valve chest; the chest and valve are generally of brass, or a cast-iron chest may be substituted, with a brass valve seating let into it. The steam in blowing through opens the valve, and all the air is driven out; but when the injection is turned on and the vacuum

formed it instantly closes, and is secured by a thumb screw, passing through the baffle plate which is sometimes fitted for throwing downwards the water expelled from the condenser.

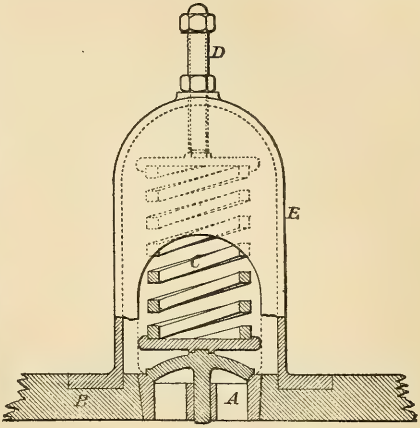


Fig. 246.—Relief Valve on Cover.

A, Valve. B, Cylinder cover. C, Spring. D, Set screw. E, Baffle cover.

The *relief valves*, placed at the top and bottom of the cylinder, are for the ejection of the water collected through priming and from the condensation of the steam. They are spindle valves, with seats of the usual form. The valve for the cylinder cover has a cap on the top, on which are placed the spring and top cap, and a set screw which passes through the cover required to prevent the hot water from scattering. The valve for the cylinder bottom is provided with a long spindle, on the top of which are placed the cap and spring, and which is screwed down by a screw passing through a bow secured to the valve casing, the baffle plate being fitted under the bottom cap. In some examples the valve is cast with a long spindle on the top of the disc, which passes through a hollow screw, fitted to a stud placed on the cylinder; between this stud and the valve there is a spiral spring with a cap at the top; by screwing up the hollow screw against this cap the spring is compressed to any desired extent; the downward pressure should be slightly in excess of the steam pressure on the valve, so that when water collects in the cylinder the piston impinges on it and forces it through the valve into the bilges. A baffle plate must be fitted to throw the hot water downwards; and these valves should be placed

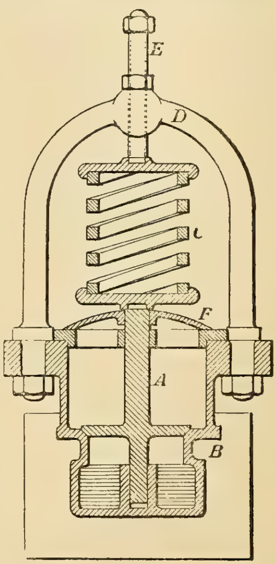


Fig. 247.—Relief Valve for Bottom of Cylinder.

A, Valve and spindle. B, Chest. C, Spring. D, Bow. E, Set screw. F, Baffle plate.

at the back of the cylinder or the part furthest removed from the starting platform, to prevent the engineer from getting scalded by the steam and hot water. A supplementary plug valve is also fitted at each end of the cylinder, for allowing the water to escape; these valves should have a handle common to both, with a pipe connection for passing the water down to the bilges; in this way the water can be blown out of the cylinder independently of the loaded spring relief valves, which are only brought into action in cases of heavy priming or other serious causes.

The *expansion valve*, when one is fitted, is placed on the top of the trunnion pipes at the side of the vessel. This valve is usually of the double-beat Cornish type, and is a very convenient form, requiring but little power to lift it. It is raised by a variable cam placed on the paddle-wheel shaft, having a balanced lever with rod passing down to the valve; on one end of this lever there is a small roller, fitted on a spindle between the jaws of the lever, having a screwed spindle so arranged that it can be turned by hand, moving the roller to suit the grade of the expansion required. Sometimes, when a certain grade of expansion is fixed upon, the valve can be lifted and shut by a rod from a crank pin placed on a wheel driven off another wheel on the paddle shaft; by moving the pin in a slot any amount of opening by valve can be obtained, the rod which connects the valve to the pin being fitted with a right and left hand screw for adjusting the length.

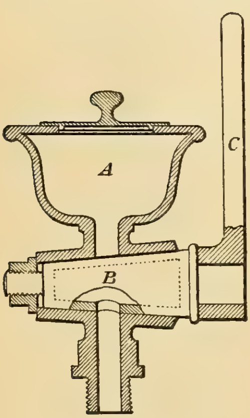


Fig. 248.—Lubricator for the Cylinder.
A, Oil cup. B, Plug tap. C, Handle.

The *throttle valve* is placed between the boiler and expansion valve, where an expansion valve is used; but where it is not, the throttle valve is placed on the top of the elbow trunnion pipe (Fig. 221). The valve is of the butterfly kind, hung equally by a central spindle passing through it, fitted with levers and rods passing along to the starting platform. The seat for the valve consists of a short flanged pipe, with gland and stuffing box for making the spindle steam tight, the other end of the spindle having a reduced pin let into a hole bored in the casting. This kind of valve is rather troublesome to get up, so as to properly fill the cylinder in which it works; two pins, one on each side, should

be left in the pattern, placed at the angle the valve is designed for, and the valve can thus be turned to fit the seating exactly.

The *lubricating cups* should be plain, having pipes passing down to the bearings, fitted with siphon wicks; and they should have covers to prevent dirt lodging in them. Some engineers cast the cups on the various parts, while others prefer light cups cast in brass. Fig. 248 shows the lubricator cup with hollow plug fitted to the cylinder cover for lubricating the piston.

SLIDE-VALVE GEAR.

The slide-valve gear for the oscillating engine differs so much from other arrangements that it requires to be treated somewhat in detail. The mode of setting out this valve motion has been already

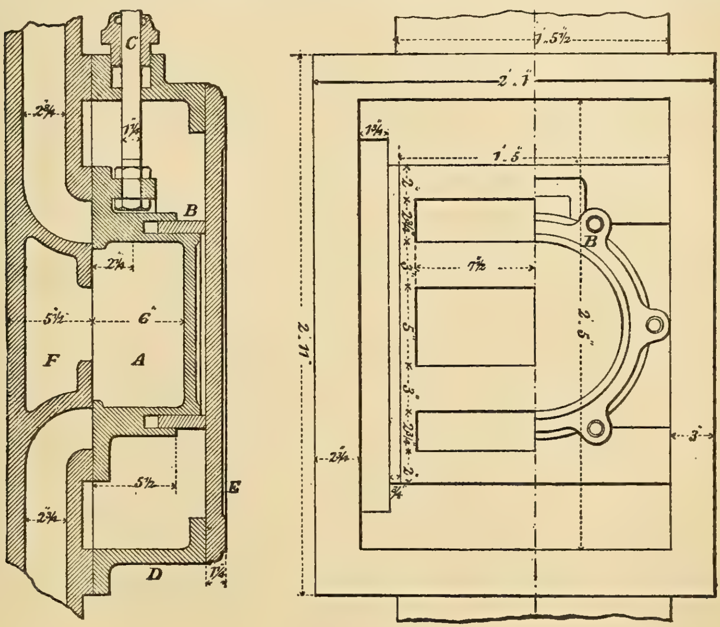


Fig. 249.—Slide Valve.[1]

A, Slide valve. B, Ring for taking off the back pressure. C, Valve spindle. D, Valve casing. E, Valve-casing cover. F, Cylinder.

described, and although the various plans adopted may differ in detail, the motion produced is the same in all. Take, for example,

[1] In this section the various figures are diminished as in working drawings for the workshop.

the case of a marine engine having a cylinder 4 feet 3 inches in diameter, and length of stroke 4 feet. The short D slide valve is usually adopted, with a packing ring on the back of the most improved description. The ports in the cylinder are not nearly so short as for direct-acting engines having the multiple-ported arrangement. There is a port at the top and bottom for the steam, in connection with one half of the passage or the belt cast on or about the centre length of the cylinder; the trunnion or pipe on which the cylinder oscillates is cast on the centre line of the belt. The outside one, or the one nearest the ship's side, in paddle-wheel engines, is for the steam, and the one nearest the centre line of the vessel is for the exhaust into the condenser, being in communication with the central ports on the cylinder. The slide valve is contained in a suitable casing bolted on the cylinder, and provided with a movable cover at the back. The inside face is planed and scraped perfectly true, so that the slide rings are steam-tight; there is a small hole bored in the back of the valve to take away any steam that may pass, which of course finds its way into the condenser. There are generally two valves, one on each side of the cylinder; such an arrangement not only reduces the size of the ports, but also balances the cylinder better. When one valve is used, a counterpoise weight, fixed on a lever, is attached to the cylinder, and oscillates with it; but such a plan, when adopted for large power, is neither so neat nor so compact as the double slide valves, although these require more working parts. At the same time, when two valves are used, the details can be made much lighter, as the area of each valve is much less. The usual mode of securing the valve spindle to the valve is by a T nut let into the valve, having a corresponding thread on the valve spindle, with a jam nut to secure it in its position; and in other arrangements a snug is cast on the valve, with a hole for the reception of the valve spindle, having nuts at the top and bottom. The centre of the exhaust port and trunnion may be taken as the starting point for setting out the valve faces, their place being the centre line of oscillation of the cylinder. The opening of the port by the valve is found by the same rule as that used in other arrangements. Thus, suppose for the cylinder 4 feet 3 inches in diameter, with stroke of 4 feet, the number of revolutions is 28 = 224 feet of piston speed per minute: we have therefore—

$$\frac{2042 \times 224}{10000} = 45{\cdot}7 \text{ square inches,}$$

which, divided by 2, equals 22·8 square inches of opening of port by valve for each. The length of the ports is found by dividing the diameter of the cylinder by 3·4, thus: $51 \div 3{\cdot}4 = 15$ inches long; and $22{\cdot}8 \div 15 = 1{\cdot}52$ inch, the opening of port by valve. The combined area of the steam ports equals $\frac{1}{25}$th, and that of the exhaust $\frac{1}{13}$th of the area of the cylinder: thus—

$$\frac{2042}{25} = 81{\cdot}6 \div 2 = 40{\cdot}8 \text{ square inches in steam port;}$$

$$\frac{2042}{13} = 157 \div 2 = 79 \text{ square inches in exhaust port.}$$

A little more or less may be allowed to secure even dimensions.

Throw of eccentric, slide gear, &c.—The oscillating engine differs from all others in having reciprocating pistons, and no connecting rod, the piston rod and crosshead being attached directly to the crank pin. We may, however, term the distance from the centre of oscillation to the crank centre the length of the connecting rod, as from A to B, and with this length as a radius, from the point B sweep the crank path, this radius is the length of the supposed connecting rod when the piston is at half stroke. It will be seen that this length varies, being greatest when the rod is vertical, the piston commencing the IN stroke, and rapidly shortening as the piston descends, until the crank pin reaches the bottom of the crank path, when the length will be simply the vertical height from B to OUT, or the commencement of the up stroke. It will thus be evident that the radius for finding the correct angle of the crank for cutting off at any part of the piston stroke varies. To explain this more fully: Divide the vertical diameter of the crank path from IN to OUT into eight equal parts, fix the point of the compasses at the point of oscillation as at B, the vertical distance to

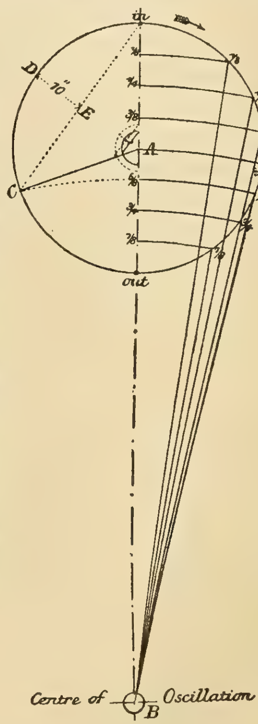


Fig. 250.—Path of Crank.

any point that may be determined on for cutting off the steam, say at five-eighths of the stroke of the piston, as from IN to OUT, is the

radius that determines the point C or centre of crank pin, when the steam is cut off at five-eighths of the piston stroke. Thus the versed sine of the chord of the arc of supply to the cylinder can be found, namely, D E, which measures nearly 10 inches. The diameter of the circle described by the centre of the eccentric can also be now found, as already described for direct motion; but as the lever for taking the valve spindle may be shorter than the one for the slot link, it is evident that the eccentric circle must have a greater diameter. Supposing this is the arrangement adopted, and the length of the lever for the valve to be 12 inches, and that for the slot link 15½ inches (those lengths can be only determined by laying down in plan the valve and gear). When it is known that the versed sine of the chord of the eccentric circle for the arc of supply is the full opening of the port by valve minus one-half of the lead, we have the following, supposing the lead to be ⅛th part of an inch: The full opening of the port by valve as already found is 1·5 inch minus $\frac{1}{16}$ inch = 1·468 inch as the versed sine of the chord of the arc described by the eccentric circle for direct motion. The diameter of the crank circle is equal to 48 inches, and the versed sine of the chord of arc of supply is 10 inches. We have therefore 10 : 48 : : 1·468 = 7·04 inches diameter of eccentric circle for direct motion, or for levers of equal length; but as the levers for working the valve are of unequal length, we have 7·04 : 12 : : 15·5 = 9·01 inches diameter of the eccentric path or full travel of the valve.

Eccentric and hoop.—The eccentric is cast in two halves and bolted together, for the convenience of taking it to pieces or placing it on the shaft. Were the eccentric placed on a plain shaft at the end, with nothing to interfere, it would be cast all in one piece; but as it is generally placed between collars turned on the shaft, at the side of the main cranks, the ring requires to be in two halves. The eccentric sheave revolves freely on the shaft, and has a catch cast on it, with a corresponding catch fixed to the shaft, so as to suit the forward and backward movements. The eccentric sheave is also fitted with a back balance, so that when the engine is reversed by hand, the eccentric rod being out of gear and the sheave being loose on the shaft, the latter is perfectly balanced, and prevented from revolving when the catch is not driving it. This is most required for engines of great power, where the sheaves being large would turn rapidly round, and being met by the catch would impart a smart blow, tending to disarrange the gear. For small

power the eccentric is fitted with a brass hoop, bolted together, for taking the eccentric rod, and large engines have the hoop forged

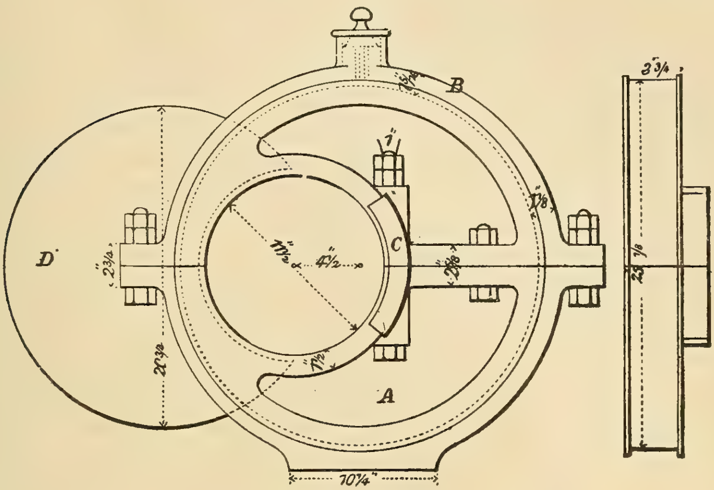


Fig. 251.—Eccentric and Hoop.

A, Eccentric. B, Hoop for do. C, Catch. D, Balance.

on the eccentric rod, and lined with brass pieces at intervals. The siphon cup for lubricating the sheave is either cast on the brass hoop, or is separate, as when the hoop and rod are forged all in one piece.

Catch on shaft.—To determine the position of the catch on the shaft to suit the forward and backward movements; the position of the eccentric centre for the forward movement being directly opposite to that for the backward movement. Draw A B, the line of crank, and describe the circle in dotted lines equal to the throw of the eccentric; then find the versed sine of the chord of arc of supply, and the point E can be fixed, that being the centre of the eccentric for the forward movement; from the point E draw a line perpendicular to A B, and produce it until it cut the eccentric path on the opposite side, that is the point or centre of the eccentric for the

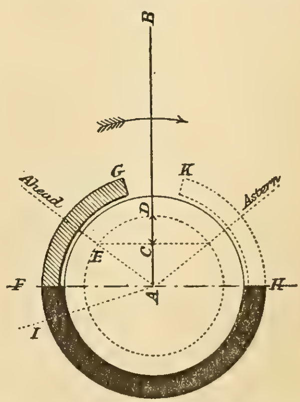


Fig. 252.—Catch for Eccentric on Shaft.

backward movement. Draw the line A E, which is the centre line of the catch on the eccentric sheave, which is set off equally on each side as represented in section, F is the forward end of catch, and G the end of catch for the backward movement. The driving catch on the shaft, represented in black, is secured by bolts. It will be seen that the line of crank is so much in advance of the point on the end of the catch on the eccentric at G, for the forward movement; and that it must be so much in advance of the point F for the backward movement. Thus, supposing the catch on the eccentric were stationary, and the crank free to go backward to the line represented at A I, it would travel through an arc the distance from H to G, when it would be down, and the catch on the shaft would be moving the eccentric the contrary way from the direction shown by the arrow, and the crank turning the paddle wheel astern. It will be seen that the catch on the eccentric sheave is placed so that the driving catch embraces one-half of the circumference of the shaft, although at times it may be less, owing to the length of the catch on the eccentric; but when convenient this position of the driving catch on the shaft is to be preferred. Thus, when the line of crank A B is in the position delineated, it will move in the direction of the arrow when the end of the catch at F is the driver; but when the end of the catch at H becomes the driver, it must move in the contrary direction. The catch on the eccentric is represented by dotted lines: the line of crank is equidistant from the points G and K. When the engine is required to move either forward or backward, the slide valve is worked by

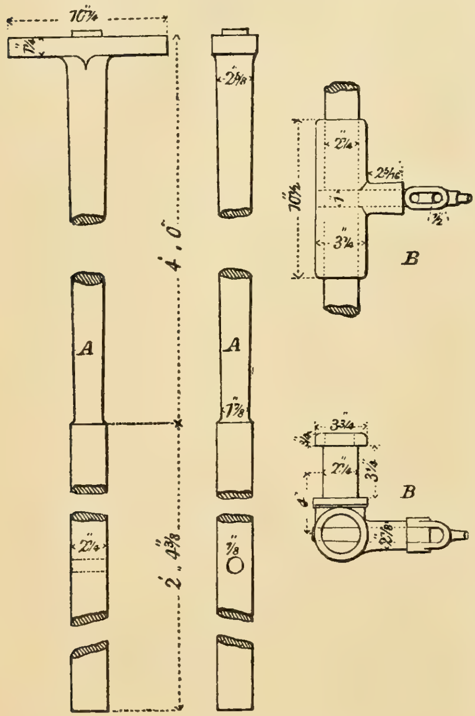


Fig. 253. — Eccentric Rod and Socket.
A, Eccentric rod. B, Socket and pin.

hand, and the eccentric accommodates itself to the catch fixed on and revolving with the main crank shaft.

Eccentric rod and valve gear.—The eccentric rod in this example (Fig. 253) is a plain round bar, with a T end for taking the eccentric strap; the end for taking the slot link passes through a long guiding piece, oscillating on the link through a hole having a brass bush. Some—indeed we may say the most—are arranged with a plain gab end, that is thrown out of gear when the engine or rather the valve is worked by hand; but in this arrangement the rod always slides in the socket, and is thrown into gear with a plain round pin passing through the socket in which the rod slides. The plain gab end, however, is usually considered preferable for large engines. The valve rod is attached to the lug cast on the valve by a screw cut on the end, with nuts on the top and bottom, which are screwed up against the lug on the valve. The top end has a slot fitted with a sliding block; a pin passes through the block, and is secured through the eye on the rocking lever. The valve rod is guided at the top by means of a bracket fitted to the cylinder. There are two rocking levers for each valve: one has a slide block working in the slot link, with a radius suited for the valve gear when placed at

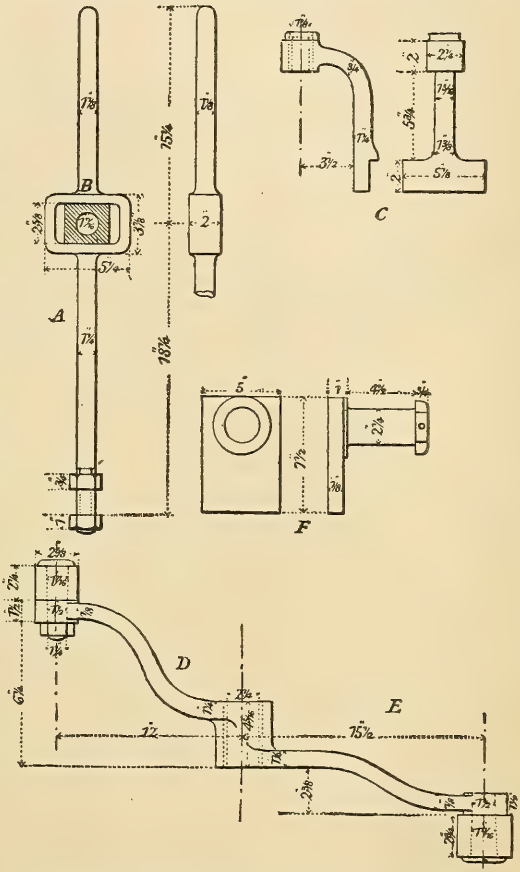


Fig. 254.—Valve Rod and Guide. Rocking Levers and Stud.
A, Valve rod. B, Block for do. C, Guide for do. D, Lever for valve. E, Lever for eccentric rod. F, Stud for levers.

half stroke; the other lever, as before stated, takes the slide valve rod. When the slide is at half stroke, the valve covering all the ports, the distance or vertical height from the centre of oscillation to the slide rod pin is the position in which the rocking levers are level. The sliding blocks on the slot link are placed slightly apart, and from the centre of the trunnions on which the cylinder oscillates to the centre of the sliding block pins is the radius of the link. The rocking levers for taking the slot link and valve spindle oscillate on a fixed centre or pin fitted to the cylinder, the rocking centres on levers being bushed with brass. This bearing is usually in the form of a pillow block, bolted to a bracket cast on the cylinder; the journal and covers are forged all in one piece, the bearing being in the middle with the levers on each side. The radius of the slot link, as before stated, is the vertical height from the centre of the trunnions to the centre of the pins on the levers, when the valve is placed at half stroke, the levers lying level. The ends of the slot link are fitted with brass guiding pieces, one of the guides having a rack or teeth cast on, working into a pinion fitted to the starting-wheel shaft. These guides are hollowed out to slide on and between the wrought-iron columns for supporting the crank-shaft framing. The slot link is likewise guided at the top, a small bracket being bolted to the headstock, through which the round part of its shank slides. The length of the slot link must be determined from the angle of oscillation at half stroke, and the necessary clearance for the sliding blocks on the levers must also be allowed for. The centre of oscillation of the socket for taking the eccentric rod has a brass bush fitted to the slot link, but when a gab end is used a plain pin is simply fastened to the link.

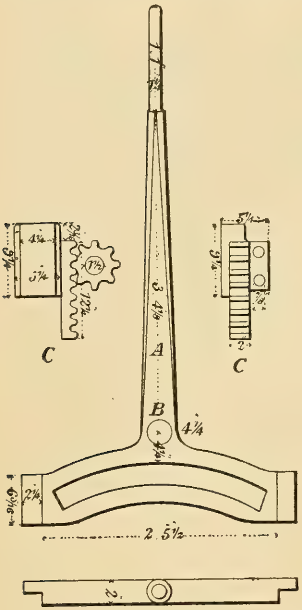


Fig. 255.—Sector and Brasses.
A, Sector and rod. B, Hole for socket. C, Lifting rack.

Starting gear.—For working the slide valve by hand, in engines of small power, a long lever handle is attached to the wrought-iron columns; this lever is fitted with a link, connected to the slot link

by means of a pin; the handle vibrates with the upward and downward motion of the sector, and the eccentric rod, fitted with a gab, is thrown out of gear by a small lever and rod, so placed that it tends to keep in the gab when in gear, and prevents it falling into gear when thrown out. In some examples springs and catches are used for the same object. Sometimes the lever handle is adopted for heavy engines, in which case it is advisable to have a socket, so as to detach the handle when the engine is working; but the better

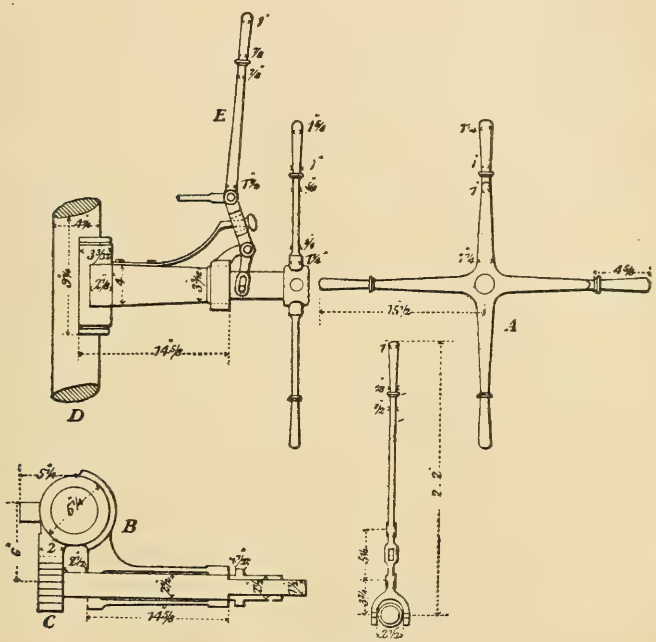


Fig. 256.—Starting Gear.

A, Starting wheel. B, Bracket. C, Pinion-rod shaft. D, Column. E, Throw-out handle.

plan is to have this part of the gearing arranged so as to be able to handle the valves at the shortest notice. A very general arrangement is by means of a pinion, working in a rack placed on one of the guides that is bolted to the sector or slot link; on the other end of the shaft for carrying the pinion is placed the starting wheel. In the example before us, the starting wheel has four arms, with a central boss, which is keyed on the shaft. The pinion is thrown in and out of gear by a lever, the same motion disengaging and putting in gear the eccentric rod. A spring detent is fitted through

a slot on the throw-out handle, a rod being attached to it and the pin which passes through the socket on which the eccentric rod slides. This arrangement of starting gear is certainly very compact, although for heavy engines we prefer the plain gab on the eccentric rod. The bracket for carrying the starting wheel, &c., for small power, is generally bolted to the columns for carrying the head-stock.

THE LINK MOTION.

The application of double eccentrics and link motion to the oscillating engine affects but little the general arrangement of the valve gear. The pin on the sector for taking the gab end of the eccentric rod, as for the single-eccentric arrangement, is used for the block on which the link slides; in fact, this pin and block may be compared to the pin and block on the slide-valve rod, in the direct applications of the link motion to the locomotive, or in horizontal direct-acting marine engines. Indeed, the oscillating engine may be considered a direct-acting engine, whether set vertically, horizontally, or lying at an angle; but as levers are interposed between the sector and valve spindle, the motion becomes indirect.

As the sector always moves in a direct line similar to the slide-valve spindle in horizontal arrangements, and as the pin for taking the block on which the link slides is fitted directly to the sector, it only remains to consider the application of the double eccentrics and link motion from this point to the centre of the main crank shaft. Thus when the levers are placed horizontally or at right angles to the valve spindle, the slide valve being at half stroke, then from the centre of the pin on the sector to the centre of the main crank shaft is the radius for describing the link, to which the double eccentrics and rods are fitted in the usual manner. So it will be understood that the double eccentrics, keyed fast on the crank shaft, having rods and link working directly in a line with the slot link or sector for taking the levers for actuating the slide-valve spindle, simply take the place of the single-eccentric rod and gab end, having means of throwing out and also of actuating the valve by hand, to suit the direction required for the forward or backward movements. The link, however, being attached to eccentrics for both the forward and backward motions, the combination of both can never err (with proper mechanism for moving it on the block which oscillates on the pin attached to the sector) in

actuating the valves as required. The valve mechanism of oscillating engines, in combination with the link motion, is beautifully simple in its multiplicity of parts, and in the science of engine-building it may be truthfully regarded as the perfection of valve gearing. It must be borne in mind that, although the positions of the centres of eccentrics are the same in relation to the centre line of crank as for direct motion, yet as the lever for taking the sector must move upwards, to depress the one for taking the valve, the positions of the eccentrics on the eccentric path are different, that for the oscillating engine being on the circumference of the path nearest the crank pin, while for direct action the centres are on the opposite circumference of the eccentric path. The mechanism for actuating the links acts simultaneously, and a very general arrangement is to have a thread cut on the shaft for taking the starting handle, fitted with a crosshead working in suitable guides, the centre of the crosshead being bored out and screwed to suit the thread on the shaft. At each end of the crosshead there is a part turned for the reception of side rods, connecting the crosshead with the main links. Thus by turning the starting wheel in either direction, the crosshead, side rods, and links are moved in the direction required. The bracket for carrying the starting-wheel shaft and for guiding the crosshead is cast all in one piece, and is fitted to the condenser on the centre line of the ship, as for paddle-wheel arrangements. This motion for actuating the link has the advantage of holding it in any position when at work, without the aid of set screws or any other appliance, which is a great desideratum when the link is used for working expansively. In some arrangements the starting wheel and shaft actuate a crosshead, generally cast in brass, on which lugs are formed for the reception of a single central rod, which takes a lever on a cross shaft, vibrating on two pillow blocks. On each end of this shaft a lever is fitted, having a pin and rod in connection with each link; thus motion is imparted, and the link put in forward or backward gear as required. In other arrangements the crosshead and guides are dispensed with, and a worm wheel substituted, which is placed on the end of the starting-wheel shaft, and works into a pinion placed central with the cross shaft, having levers and rods in connection with the link, as already described. Sometimes the bracket for carrying the starting-wheel shaft in this arrangement is simply a pipe bushed at each end, cast along with the hot well, to which the cross shaft has pillow blocks also. In fact, the main

thing to be studied in the mechanism for actuating the link motion is the side rods for taking the link: let them be of sufficient length, so that the versed sine of the chord of the arc of oscillation may not affect the link in relation to its block; because, when they are made too short, a sliding action takes place, which in some instances seriously affects the proper working of the valve. When this point is duly attended to, power has only to be applied to the lifting or reversing rods, and the mechanism for applying this power should in all cases be as simple as possible. For small engines, a cross shaft with pillow blocks cast on the condenser, and having levers and rods at each end, actuated by a plain lever handle, and with quadrant and catch similar to the locomotive engine, is as good an arrangement as can be adopted.

The link generally used is of the solid type, slotted to receive the block on the sector, all of which are made to the proper radius. The lugs for taking the eccentric rods are forged on, but in some instances lugs are wanting, and the rods are simply attached to the ends of the link. The former is the better arrangement, as the pin on the eccentric rod is nearly in a line with the pin for taking the link block, thus direct motion is obtained; while in the latter arrangement, the eccentric rod pin is all to the one side, and in addition a larger eccentric sheave is required, which is not desirable. The pin on the link for taking the lifting or reversing rods is placed midway between the eccentric-rod ends, on the radius line of the link, and it is forged on a cross bar secured to the link by rivets. In some cases the eccentric-rod straps are forged along with the rods, having a lining of brass, and are secured on the eccentric sheaves with bolts and nuts; in others they are cast in brass, and the rod attached by means of a T piece forged on the end, with suitable bolts and nuts, lock nuts, and securing split pins. The eccentric sheaves are cast in two pieces, accurately fitted together, and bolted similarly to the sheaves for single-eccentric arrangements; this is done for the convenience of getting them on or off the shaft, but where circumstances will allow of it, the sheaves are better cast in one piece, which simplifies the manufacture.

SPECIFIC NOTICES OF MARINE ENGINES.

The *oscillating* engines of the *Great Eastern* are the largest yet made, there being four paddle cylinders of 74 inches diameter and 14 feet stroke; the diameter of the paddle wheels is 58 feet.

The oscillating engines of the Clyde river steamer *Columba* are probably the largest yet used in any river steamer, each of the two cylinders being 53 inches in diameter, and the stroke 5 ft. 6 in.

The *Lord of the Isles*, another large Clyde river steamer, has two diagonal oscillating cylinders, working on the same crank pin. The diameter of these cylinders is 46 inches, with a 5 feet 6 inches stroke. These steamers are fitted with surface condensers.

In the *Post Boy*, a vessel of 65 tons and 20 horse-power, built on the Clyde in 1820, the late Mr. David Napier appears to have tried a surface condenser, consisting of a series of small copper tubes through which the steam passed, and was condensed by a circulation of cold water on the outside of the tubes.

The *Fairy Queen*, the first iron steamer plying on the Clyde, launched in 1831, had an oscillating engine.

The *steeple* engine, first introduced on the Clyde about 1836 by Mr. David Napier, is a convenient form of engine for river boats. It consists essentially in an overhung triangular frame from the crosshead, on which hangs the connecting rod. This frame and rod are connected with the piston by either one or more piston rods. In the earlier forms one rod was commonly fixed to the lower part of the triangular frame, in other forms two and often four piston rods are used.

The *side-lever* engine was extensively used in paddle-wheel steamers, the arrangement being very much that of an inverted beam engine.

The first paddle steamer to cross the Atlantic from Britain was the *Sirius*, built at Leith in 1837, and engined by Messrs. Wingate & Co. of Glasgow. The *Great Western*, built at Bristol, also made the passage, the two arriving in New York about the same time. The *Sirius* measured 178 feet long by 25 feet 8 in. beam, depth 18 feet 3 in., and was 450 tons register. She was fitted with two side-lever engines of 270 horse-power; diameter of cylinder 60 in., stroke 6 feet; paddle-wheels 24 feet diameter with twenty-two floats, and appears to have had Hall's surface condensers.

The Cunard steamer *Scotia*, the last great ocean-going paddle-

wheel vessel built, was fitted with a pair of side-lever engines, the diameter of cylinders being 100 inches, with a stroke of 12 feet. The diameter of paddle wheels was 40 feet.

A specimen of the early side-lever engine may still be seen placed on a pedestal at Dumbarton pier on the Clyde. It is the first marine engine made in 1824 by Mr. Robert Napier, the well-known Clyde engineer, for the steamer *Leven.*

Trunk engines were introduced by Penn, and have been much used in H.M. navy. The piston rod is made hollow, and the connecting rod being centered well down in it a saving of room is effected.

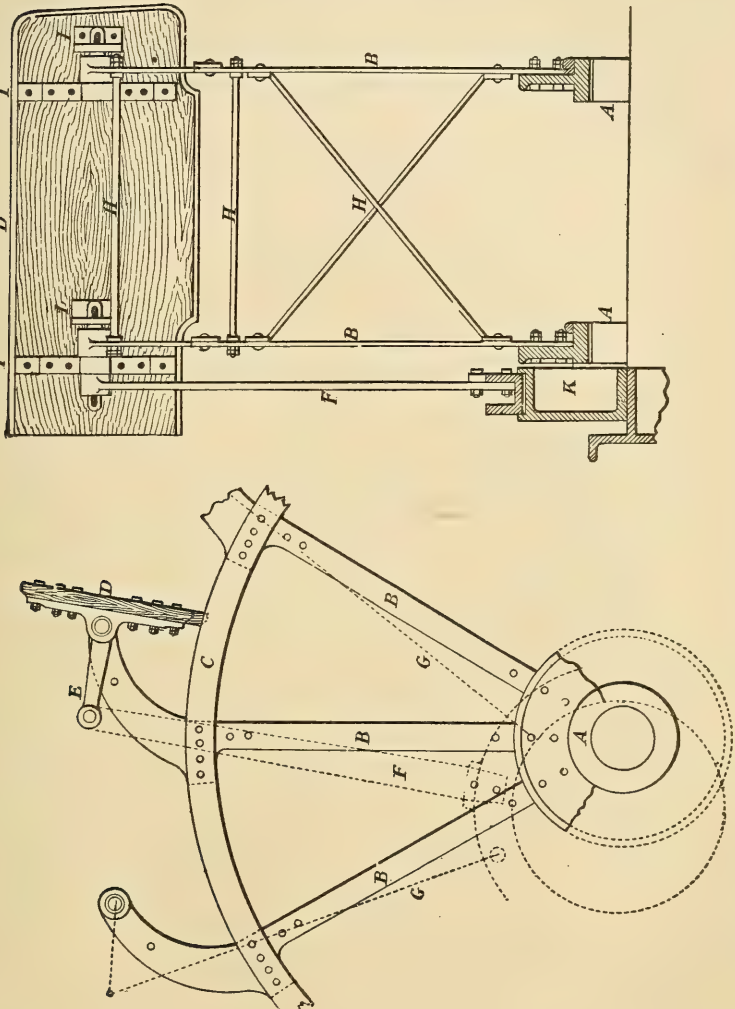
A form of engine now common on Clyde river steamers is the *diagonal direct-acting.* In these engines the piston rod is attached to a crosshead working in slides, and from this crosshead the connecting rod stretches to the crank pin. It may be of interest here to state that the first efficiently steam-propelled vessel, the *Charlotte Dundas,* was fitted with a horizontal direct-acting engine; this vessel was tried successfully on the Forth and Clyde Canal in 1802.

In many of the earlier steam vessels, from the *Comet* downwards, spur-wheel gearing was used to connect the engine with the paddle shaft. A few details of the size of the *Comet* may be interesting. She was about 25 tons burden, and was built for Henry Bell in 1812 by Mr. John Wood of Port-Glasgow. She measured 42 feet long, 40 feet keel, and 11 feet broad, with 5 feet 6 in. draft of water. The engine, made by John Robertson of Glasgow, was a condensing one of 3 horse-power, the diameter of cylinder being 11 inches, and the stroke 16 inches, the crank working below the cylinder; the engine-shaft, connected with a fly-wheel, is said to have been of cast-iron, and 3½ in. square. The engine was fitted on board before launching and steam raised. At first the *Comet* was fitted with two pairs of paddles, 7 feet diameter, with spur-wheels of 3½ feet diameter; but soon afterwards she was lengthened to 60 feet, and a new engine with a single pair of paddles substituted, the speed being now greatly improved, and reaching from five to six miles an hour. The diameter of the cylinder is stated as 12½ inches and the horse-power 4.

THE PADDLE WHEEL.

The paddle wheels now in use are generally of the feathering type, the floats entering and leaving the water almost vertically; having thus a better hold of the water than the fixed floats, which enter obliquely,

and whose full propelling area is only attained when the arms to which they are bolted are vertical. Thus when fixed the floats depress the water on entering, and tend to lift it when leaving, and



Figs. 257, 258.—Feathering Paddle Wheel, with outside bearing.—A, Paddle-wheel centre boss. B B, Arms. C, Rim. D, Float. E, Arm for float. F, Driving rod. G G, Radial rods. H H, Stays. I I, Brackets. K, Eccentric bolted to the ship's side.

to obviate this difficulty each float was formerly stepped, or made in two or more separate pieces, placed one before another. This plan, however, is now become almost obsolete; the feathering floats, although somewhat complicated, being generally adopted for all

fast river steamers, and the screw superseding the paddle wheel almost universally for ocean-going steamers.

To understand the action of the feathering paddle wheel we have to consider each float free to oscillate on pins passing through brackets forged on the paddle arms; on one of these journals an arm is fixed, and a rod for each float is attached to a pin on the end of each arm, the arms being all connected to a strap (Fig. 259), which is free to revolve on a sheave (Fig. 260) placed eccentrically with the main shaft. One

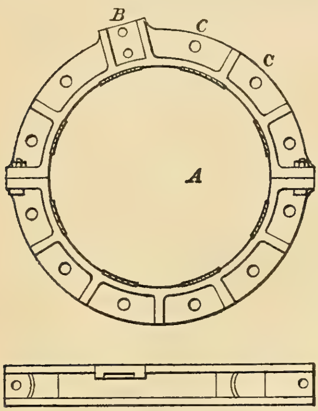


Fig. 259.—Eccentric Strap.

A, Strap with brass lining pieces. B, Seat for driving rod. C C, Holes for radial rods.

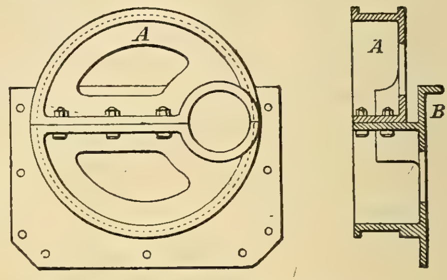


Fig. 260.—Eccentric Sheave for Paddle Wheel.

A, Eccentric. B, Flange for bolting it to the ship's side.

of these connecting rods is the driver, and is firmly secured to the eccentric strap in a way similar to an eccentric rod for the valve motion. When the paddle wheel is overhung, with one pillow block at the side of the vessel, this bearing being supported with a wrought-iron bracket rivetted to the side of the ship, the eccentric sheave is secured at the end of the pillow block; and when the paddle wheel is supported with an outside bearing bolted to the sponsons, the eccentric sheave is bolted to the side of the ship direct. In setting out the mechanism, we consider the position of the driving float, as we may term it; at its deepest immersion it is quite vertical, and as the rod from the arm that is fixed on the float is secured to the eccentric strap, as the paddle wheel revolves the

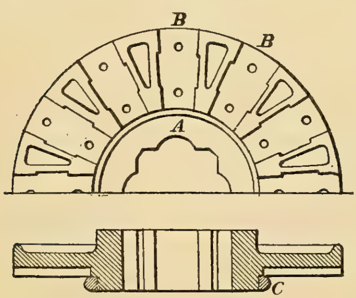


Fig. 261.—Boss for Paddle-wheel Arms.

A, Boss. B B, Seats for arms. C, Wrought-iron ring.

eccentric ring is dragged round, and the driving float always assumes that vertical position at the deepest immersion, as indeed do all the other floats, the only difference being that they are secured to pins on the eccentric strap, instead of being firmly bolted to it; thus when the centre line of the eccentric is placed on a level line, all the floats assume different angles, but at the same time each float enters the water in a slightly oblique direction, and leaves it vertically. It is obvious that the floats must not be placed too closely

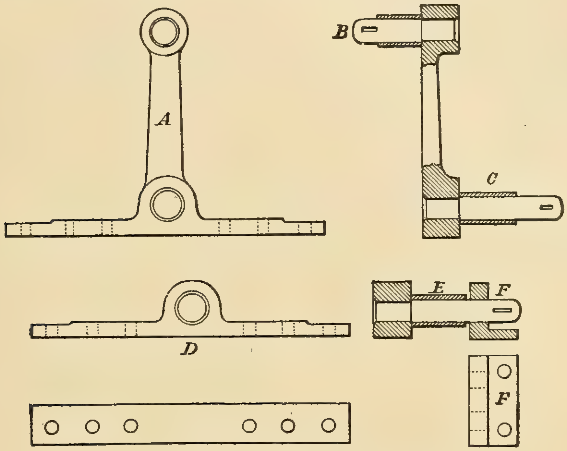


Fig. 262.—Arm and Brackets for Floats.

A, Arm and bracket. B, Pin and brass bush. C, Brass bush. D, Bracket. E, Pin and brass bush. F, Bracket.

together,—three immersed at one time is considered sufficient; if closer packed they only disturb the water and clog the action of the wheels. Some builders prefer simply an eccentric or a circular sheave (Figs. 264 and 265), revolving on a pin firmly secured to the sponsons, and fixed aft of the centre of the paddle shaft in a horizontal line; the sheave is formed of two flanges, with a projecting piece for the driving arm, and pins for all the other rods: in action this form is similar to the foregoing. All the moving joints must be bushed with brass, both on the pins and eyes, to preserve and keep fair the various joints; unless this is properly attended to corrosion would set in, and soon destroy the feathering paddle wheel.

The *pillow block* for the overhung paddle wheel is a plain casting fitted with a cap, the bolts for securing which pass down through

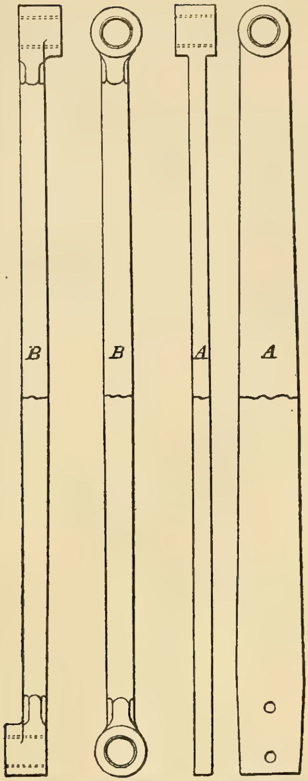


Fig. 263.—Eccentric rod, &c., for Floats.
A, Driving or eccentric rod. B, Radial rod.

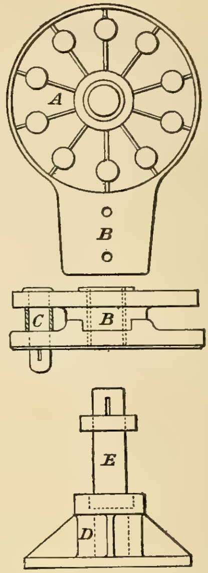


Fig. 264.—Eccentric and Pin for Paddle Wheel.
A, Eccentric. B, Part for driving rod. C, Pin for radial rod. D, Bracket bolted to the sponson. E, Pin for eccentric.

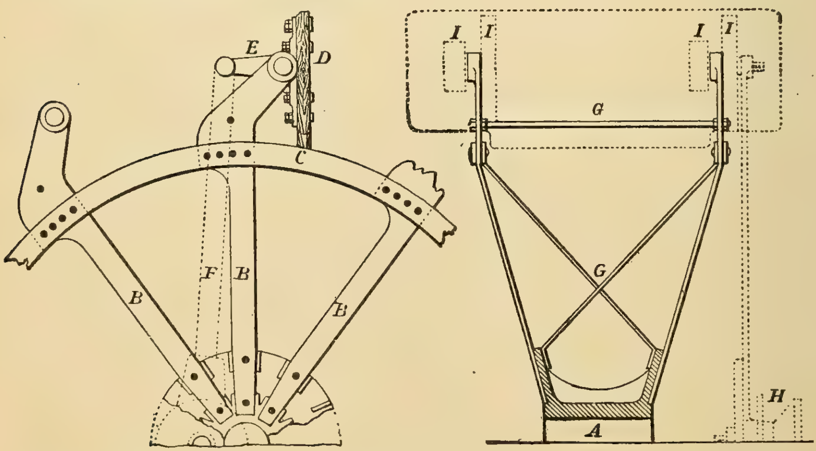


Fig. 265.—Overhung Feathering Paddle Wheel.—A, Boss. B B, Arms. C, Rim. D, Float. E, Arm for float. F, Driving rod. G G, Stays. H, Eccentric and pin bolted to the sponson. I I, Brackets.

the bracket fitted to the side of the ship; the sole of the block is also bolted to the bracket, as shown in Fig. 266.

In some ocean steamers the paddle-wheel shaft was arranged so that it could be disconnected from the engine when the ship was under sail alone. The simplest plan for effecting this is by fitting a disc on the end of the shaft, instead of the usual crank, the disc having a hoop with a projecting lug piece for taking the crank pin; the hoop is forged all in one piece, and is held in position with a fast-and-loose collar on the round disc; the grip is attained by friction blocks, or wedges, firmly screwed between the disc and the hoop on the circumferential line, the disc being keyed to the shaft with one or more keys. Therefore when the friction blocks are released, the shaft and disc revolve independently of the engine, the motion of the vessel through the water, driven by the sails, causing the paddle wheels to revolve. In this way the progress of the vessel is not impeded so much as it would be were the floats stationary, and offering a great resistance for the wind to overcome.

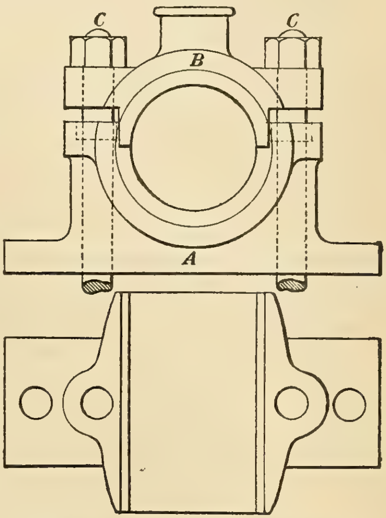


Fig. 266.—Pillow Block for Paddle Wheel.
A, Pillow Block. B, Cap for do. C C, Holding-down bolts.

The paddle wheel of a ship may be compared to an ordinary carriage wheel, any point in the circumference describing a *cycloid* curve. The circumferential distance a carriage wheel travels over is an exact measure of the distance the carriage has gone; but as the paddle wheel acts in a yielding fluid, the distance travelled over by it is not an exact measure of the vessel's progress through the water. The difference is termed the *slip* of the paddle, and ranges from one-fourth to one-fifth of the circumferential distance the paddle wheel has gone over, which of course must be measured on the mean centre of propulsion of the floats, and not on the extreme diameter.

The reciprocating parts of marine engines are generally balanced with suitable weights, and notwithstanding that the cylinders of

the oscillating engine are properly balanced, yet the pistons and cranks must be also balanced by a metal float fitted on each paddle wheel, although that is partly done by the air-pump bucket and its adjuncts, the crank of which divides the path of the main cranks into three parts—that is to say, the cylinder cranks being at right angles, the line of the air-pump crank divides the longest circumferential line between the main crank pin centres into equal parts.

The feathering paddle wheel was tried at various times, but not with much success till about the year 1850. Fixed floats were mostly used in ocean-going steamers, being considered less liable to derangement.

Two pairs of paddle wheels have been proposed to be used. The *Comet* had at first, as we have said (p. 378), two pairs, but these were removed, and a single pair substituted. Single wheels at the stern and amidship, as in twin-boat arrangements, have also been tried, as also endless chains with floats attached, passing round a couple of drums driven by the engine. Iron floats have sometimes been used instead of wood floats in paddle wheels.

Besides the screw propeller, to be afterwards treated of, the propulsion of vessels by a jet of water has been tried. This contrivance is known as "Ruthven's Hydraulic Propeller," and consists of a turbine-like wheel driven by a steam engine. The water is first of all drawn in by the turbine, and then driven out at openings along the ship's side in such a manner as to keep up a constant stream. A vessel named the *Nautilus*, furnished with Ruthven's propeller, had a trial trip on the Thames in 1868. She ran at the rate of 13·5 and 7·2 miles per hour with and against the tide respectively, or at an average speed of 10·35 miles per hour; and when going at full speed, with both wind and tide in her favour, she was made, by reversing the valves, to stop dead in less than ten seconds and in about a quarter of her length. The plan has also been tried in H.M. iron-clad gun-boat *Waterwitch*, of about 780 tons, with some success. It has also been tried in the United States of America, but without commending itself as against either the paddle or the screw.

It should be noted in all questions of propulsion that the principle involved is the putting in motion of a quantity of water in a backward direction, the *reaction* from which action is the propulsive effect. Professor Rankine gives the following rule for the thrust

of a propeller, whether paddle, screw, or jet, *in lbs.*:—"Multiply together the transverse sectional area in square feet of the stream driven astern by the propeller; the speed of that stream *relatively to the ship*, in knots; the *real slip*, or part of that speed, which is impressed on that stream by the propeller, also in knots; and the constant 5·66 for sea water and 5·5 for fresh water."

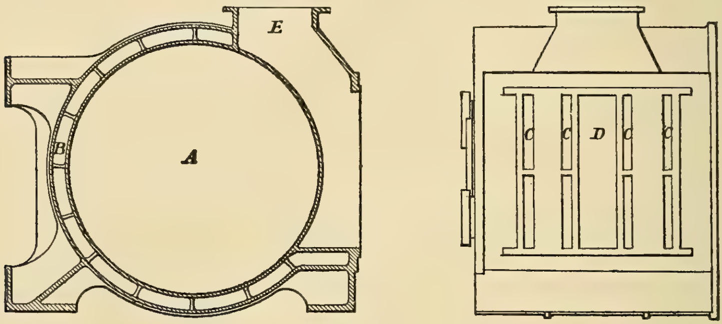
HORIZONTAL DIRECT-ACTING AND RETURN CONNECTING-ROD ENGINES.

In these engines the cylinders are placed side by side, as in the locomotive engine, and the steam valves are worked directly off the cranked shaft by double eccentrics and link motion. The condensers are placed on the opposite side of the shaft for return connecting-rod engines; they are fitted with guides for the cross-heads; the piston rods are secured to arms forged on the crosshead, and are so arranged for the rods crossing the cranked shaft, one above and the other under the shaft. The connecting rod by this arrangement is not in a direct line with the piston rods, but goes backwards, while the piston rods are connecting to the piston in a forward line crossing the main shaft of the engine.

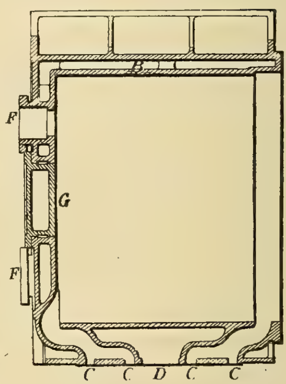
The distance between the centres of the *cylinders* in these engines is regulated by the arrangement of the air pumps and valves. When the air pumps are close together on each side of the centre frame, the distance between the centres is greater than when the air pumps and adjuncts are placed further apart, close to the outer frames; however, it is not a good plan to contract the water passages in connection with the air pumps and condenser to gain a few inches between the centres of the cylinders. Steam jackets are generally used, cast along with the cylinder; the fronts and cylinder covers are also made double, so that the steam from the boiler freely circulates all round the cylinder, and the full pressure is better maintained on the piston, a higher indicated measure being given out than by an unjacketed cylinder. To prevent condensation in the steam casing the outside of the cylinder should be covered with felt, and then overlaid with lagging or narrow strips of wood, which are secured to wooden hoops, bolted to the strengthening ribs left in the casting. The passages for the steam and exhaust are arranged

for double-ported valves, that is to say, there are two steam passages at each end, and one central passage, in communication with the condenser. The joints should be placed metal to metal, all planed or surfaced in the boring lathe, and the rubbing surfaces

Figs. 267–268.—Cylinder.[1]



for the slide valve should also be carefully planed as smooth as possible, and then scraped to a face plate, before the slide valve is fitted, which should also be carefully faced on the plate, and thus both surfaces will only require a finishing touch. All the other joints are made steam-tight by interposing a thin coating of red lead. The joints being thus metallic, the working of the engine has but little tendency to loosen them, which might otherwise happen were an elastic joint adopted. On



the front end of the cylinder a central manhole must be left, for the boring bar to pass through; with single piston rods there is a small cover with stuffing box and gland, but with double or more piston rods a plain cover is fitted; holes are also left in the front end of the cylinder for the air-pump rod, with suitable glands and bushes, and a hole at the bottom for the relief valve; narrow fitting strips should be left at those parts where the main framing abuts against the other fittings. The cylinders are bolted together, with flanges placed between them, having narrow fitting strips all round, which are carefully planed; all the holes should be drilled, and rimed out to make

[1] A, Cylinder. B, Annular steam space. C C, Steam ports. D, Exhaust port. E, Exhaust branch. F F, Piston-rod glands. G, Cover for hole for boring bar.

them quite fair; by this means the turned bolts fit the holes exactly, and good firm work is obtained. The flanges at the top and bottom are planed, and the latter are cast along with the flanges for bolting down the cylinder on the keelsons. Raised parts should be left on the casting at all the places where the bolts are arranged; in this way an even face is easily made for screwing the nuts up against, which helps to secure first-rate work.

The *cylinder cover* should be a deep and strongly-ribbed casting, fitted with a central manhole door, through which the bolts of the piston and piston rods may be inspected without requiring to break the joint of the cover, which is a somewhat difficult task at sea,

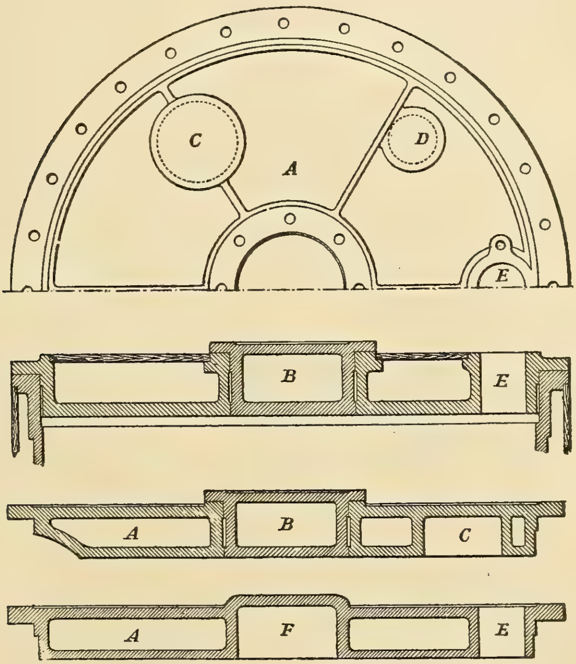


Fig. 269.—Cylinder Covers.

A A, Covers. B B, Manhole covers. C C, Recesses for piston-rod nuts. D, Recess for air-pump rod nut. E, Hole for relief. F, Recess for single piston-rod nut.

more especially with large and heavy covers. The number of bolts should be carefully calculated, so as not to have a great preponderance of strength in that part, for in the event of the cover receiving a violent blow from the piston striking against water in the cylinder due to violent priming, when the flanges in the cylinder

and cover are properly proportioned the bolts should rather give than a breakage occur. A hole is left at the bottom of the cover for the relief valve, similar to that in the front of the cylinder.

The *stuffing boxes* for the piston rods are fitted with a lantern or hollow distance piece, with an extra light gland placed on the main one, the stuffing box of which is packed in the usual manner. The lantern brass is placed in the outside stuffing box, and then a gasket of hemp or other packing is placed on the back of it, and screwed up with the light gland. The use of this lantern brass is to leave a space all round the piston rod for containing the lubricating oil; the piston rod has thus a ring of oil all round, which is kept in the space by the hemp packing, and prevented from dropping down and running to waste. The main glands are generally screwed down with plain bolts and nuts; but in fast-going engines a risk attends this method, as the gland is liable to be pressed against the side of the rod, and thereby to throw an undue strain on the piston

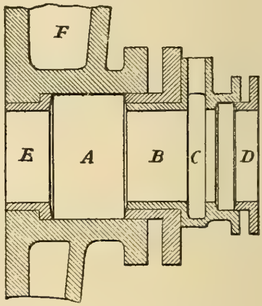


Fig. 270.—Piston-rod Gland with Lantern Brass.

A, Packing space. B, Gland. C, Oil space. D, Gland. E, Bush. F, Cylinder cover.

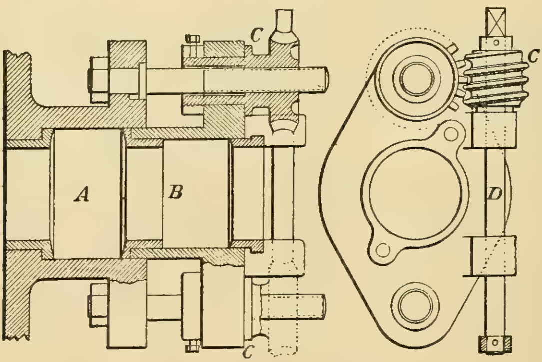


Fig. 271.—Piston-rod Gland with Adjusting Gear.

A, Packing space. B, Gland. CC, Worm wheels and pinions. D, Spindle.

rods. In order to effect a parallel strain on the packing, as well as to be able to tighten up the gland when the engines are in motion, two large bolts are used, with worm wheels and pinions on each, and a spindle connecting them; thus by one movement the gland can be tightened up in a parallel manner. In some engines of the

direct-acting type the packing gland for the piston rod is recessed into the end of the cylinder, the end being curved, as well as the piston and cover: by this means a slight gain is obtained in the length of the main connecting rod, but otherwise it affords no advantage, and the patterns are more difficult to make.

The *exhaust pipe* in communication with the condenser is cast along with the cylinder, and can be made of any required shape, provided the area is sufficient. The circular shape, however, is the strongest and best for that part of the exhaust pipe which joins the thin copper pipe leading to the condenser, as the latter pipe forms really part of the condenser, and unless it were made circular it would collapse with the atmospheric pressure. The ends and covers of the cylinder must be strongly ribbed in the casting with feathers radiating from the centre; from this not being properly attended to, the pulsation of the cast iron in some covers is quite visible at each stroke of the piston. This bending and unbending of the metal of course deteriorates its molecular particles, and when any undue strain comes upon the cover from excessive priming, there is danger of its becoming fractured, or indeed of being blown out altogether, as has happened to many covers and ends. A small branch pipe should be cast on the exhaust pipe, for the blow-through valve, which is connected to the valve casing or the steam pipe, according to the locality of other details. Small bosses should also be cast on the bottom of the cylinder at each end, to which small plug valves are fixed for allowing the water to escape out of the cylinder before starting; these valves are connected together with levers and rods, one handle serving to open them both. All small fittings that are intended to be fixed on the cylinder should have facing strips cast on, which tends to lessen the labour in the workshop. To effect this important object more completely, some makers have cast the cylinders together, but the risk in this method is considerable. We have seen castings of this kind that looked sound, and one of the cylinders on being bored out presented a good surface, but the other was quite porous and full of blown holes; both of the cylinders of course requiring to be broken up as useless. This fact may deter many from trying such a plan, at least for large cylinders, yet for small ones the advantages are great, and the risk proportionately less. Care should be taken, however, that the metal be neither too soft nor too hard, more especially the latter, as extremely hard castings should be avoided,

particularly for great steam pressure. Many cylinders cast too hard have cracked in all directions after being but a very short time in use, owing, it is considered, to the unequal expansion of the metal. The core of the casting has been removed in the moulding pit to cool the inside of the cylinder, which makes this portion harder than the outside portions, and strains the metal forming the whole casting, rendering it brittle, and very liable to give way under steam pressure in those parts where the expansion of the metal is the greatest. Good metal only should be employed, and the casting allowed to cool slowly.

The *slide valve* is a very important detail, and is generally of the double-ported type, although treble ports are sometimes introduced. Considering the great size that is required for direct-acting engines, this valve should be well proportioned, and all its gear of a strong and substantial make. Some engineers still prefer valve facings of hard brass, secured to the cylinder face by screwed pins rivetted over; and even steel facings have been successfully used for high-pressure marine engines. There can be no doubt that when

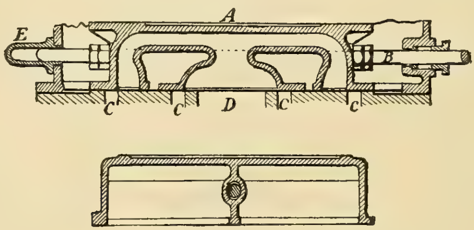


Fig. 272.—Slide Valve, with rod passing through it.

A, Slide valve. B, Valve rod. C C, Steam ports. D, Exhaust port. E, Guide for valve rod.

the slide valve is placed on its edge, cast-iron surfaces are found to answer, when properly provided with means for running off the water that collects in the valve casing when the engines are standing, still, as the moisture must impair the cast-iron surfaces, and the slightest unevenness of the facings will pass steam, it is perhaps advisable in some cases to use brass surfaces. Perfection in detail is doubtless the main thing to be studied, even although it may entail at first considerable cost in construction. Various methods are adopted for securing the valve rod to the valve. In some engines the rod passes through a tube cast along with the valve, and is secured by a collar at one end of the rod and two nuts at the other end; in others again the valve

rod is screwed (Fig. 272), having a raised screwed part at both ends and double nuts; by this means the valve can be very accurately set at any time. The hole through the valve should be slightly

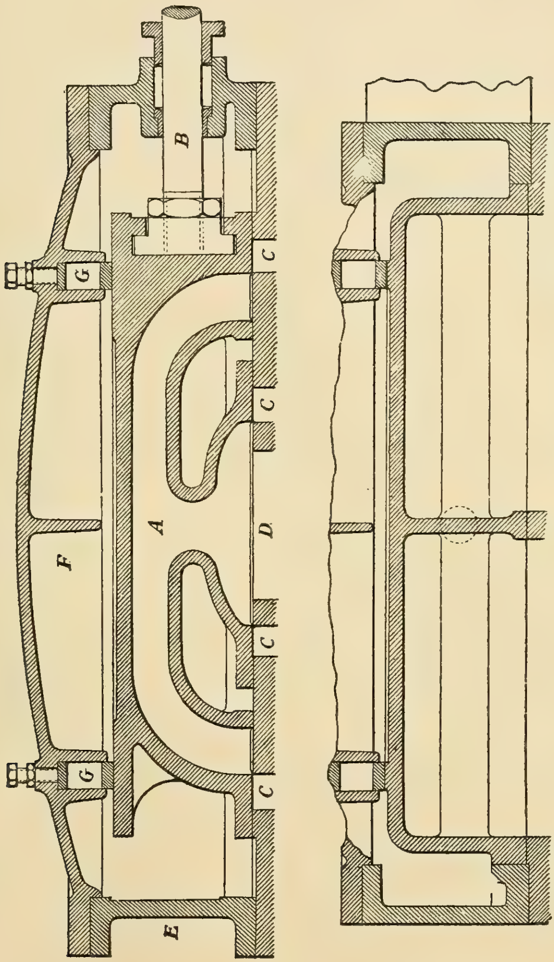


Fig. 273.—Slide Valve, with T nut for Rod, and Packing Rings recessed in the Valve-casing Cover.
A, Slide valve. B, Valve rod with T nut. C C, Steam ports. D, Exhaust port. E, Valve casing.
F, Valve-casing cover. G G, Rings for taking off the back pressure.

oblong, to allow for the wear and close contact between the faces of the valve and cylinder. The valve rod, in some examples, is guided at the end through a hollow brass pipe, or a stuffing box and gland, similar to the front end. In other arrangements the end of the valve spindle is screwed into a nut recessed in the valve casing; the thrust is taken on the end of the nut, and the pull on projections

formed on the nut of a T shape; a thin jam nut is fitted, so as thoroughly to bind the rod and nut together: both of these nuts should be made of steel, and case-hardened. Another method of securing the valve rod is by a cotter passing through a boss cast on the valve, the cotter being fitted with a split pin to prevent it shaking loose. With the view of relieving the rod and adjuncts from the severe strain caused by the steam acting on the back of the valve, packing rings are fitted to the valve, or rings of metal pressed up against it; in the former case the ring is recessed in the valve, and pressed up with springs against a planed piece on the valve-casing cover; in the latter, the ring is recessed in the valve-casing cover, and pressed up with set screws against the valve. The object of both of these plans is to obtain a large area on the back of the valve from which the steam in the casing is excluded by means of the metallic rings, which of course do not leave such large surfaces for the steam pressure to act upon. This hollow space is sometimes fitted with a small pipe in communication with the condenser; thus the valve is partly drawn from the face as it were by the vacuum.

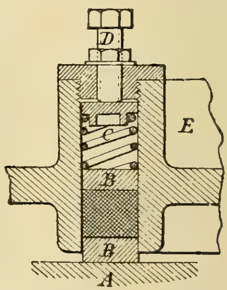


Fig. 274.—Spring and Packing for Slide Valve.

A, Slide valve. B B, Rings for taking off the back pressure. C, Spring. D, Set screw. E, Valve-casing cover.

The *valve casing* is a separate open frame, cast with flanges for securing it to the cylinder. It is very rarely cast along with the cylinder, at least for heavy engines; although for engines of small power this plan may be advantageously adopted. The casing cover is generally cast with a recessed ring, and bosses for springs, which are accurately turned out for the reception of the packing rings and springs; it is of a curved shape, quite plain on the outside, and well ribbed on the inside, which prevents the dust from lodging, and the plain exterior surface is easily wiped down,—an important consideration in all the parts of a marine engine, as that operation can only be properly attended to when the vessel is in port. A snug should be cast along with the cover, having a hole bored in it for a wrought-iron shackle and pin, to which blocks and tackle can be secured when taking off and putting on the heavy covers.

The branch for the steam pipe is generally placed at the back of the valve casing, and is cast along with it, the flanges looking towards each other from cylinder to cylinder. At one end there

is a stuffing box and gland, and at the other end the copper pipe is bolted to a plain flange; while the part in the gland is quite loose, expanding and contracting with the varying pressure.

Eccentric and link motion.—Various descriptions of valve gear are in use, but the one generally adopted is the double eccentrics and link motion. This is only introduced as a sure means of handling the engines, and is but rarely used for working expansively, as in the locomotive, for the obvious reason that were the slide valve travel-

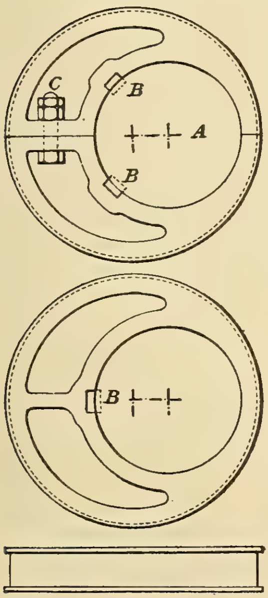


Fig. 275.—Eccentric Sheaves.
A, Eccentric. B B, Keys. C, Bolt for eccentric.

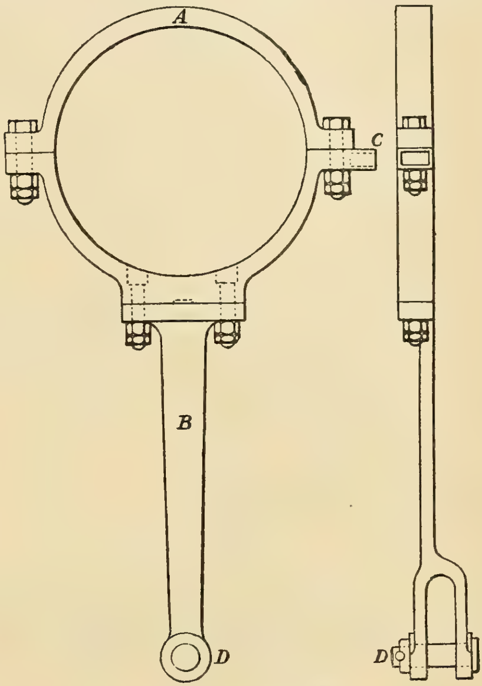


Fig. 276.—Eccentric Strap and Rod.
A, Eccentric strap. B, Rod. C, Lubricator cup. D, Jaw and pin for link.

ling only a small portion of its stroke, and kept running for weeks in this reduced grade, a groove would be formed on the cylinder face, which would pass steam into the condenser when the valve or link was put in full gear, and so impair the vacuum; and it thus becomes imperative to have a separate expansion valve. In the example in Fig. 275 the eccentrics are cast in two halves and secured with bolts and nuts, in other examples they are cast solid; in both cases they are firmly secured to the shaft by keys, as shown.

The eccentric strap (Fig. 276) is of brass, having a wrought-iron rod with T-piece forged on one end, secured to the strap by bolts and nuts, the heads of the bolts being recessed in the strap; on the other end a jaw is formed for taking the link. The latter has eyes forged on and fitted with brasses and set screws for adjusting the wear on the eccentric-rod pins; the suspending pin for the link is formed with a palm, which is securely rivetted to the link.

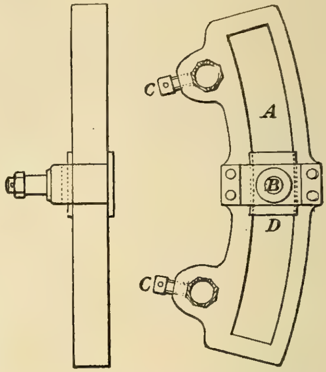


Fig. 277.—Link:

A, Link. B, Suspending pin. C C, Eyes for eccentric rods. D, Block on slide-valve rod.

The various arrangements of valve mechanism have been treated more fully in a former part of this Work (see page 110).

When *gridiron expansion valves* are used, the seating on the valve face is cast along with the casing, making a very compact arrangement. The valve in Fig. 278 is cast in brass, and is worked by a single eccentric and varying link. In some examples the valve is circular;

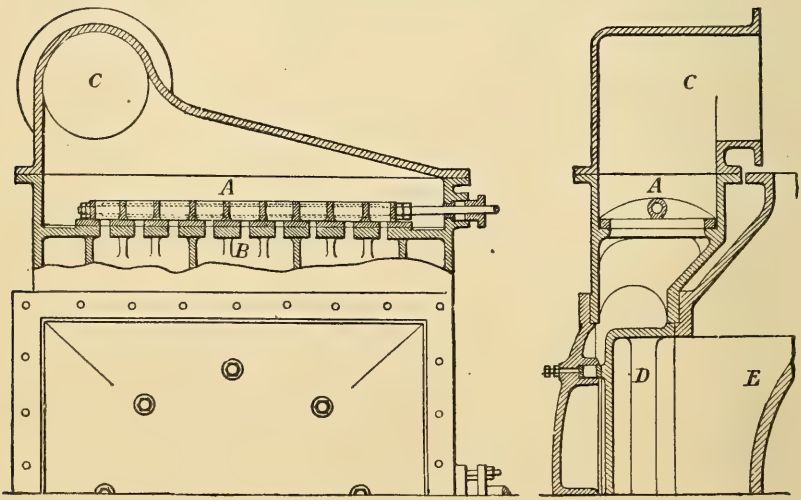


Fig. 278.—Gridiron Expansion Valves.

A, Expansion valve. B, Facing for do. C, Steam pipe. D, Main slide valve. E, Cylinder.

by adopting this shape the steam pressure is taken off the back, and the valve is consequently more easily handled.

The *throttle valve* is generally of the butterfly type, and is located between the expansion valve and the boiler, having hand gear for each valve passing along to the starting platform. Some engineers use only one handle for both valves, but this arrangement is not advisable, as one engine or cylinder may require more or less throttling than the other, although the cylinders are lying quite close together. A small plug or other valve is fitted between the gridiron expansion casing and the main valve casing, by which steam can be admitted from the one to the other, in the event of the engines stopping at a part of the stroke where the expansion valve covers the ports, and it would be difficult to start again without this auxiliary valve.

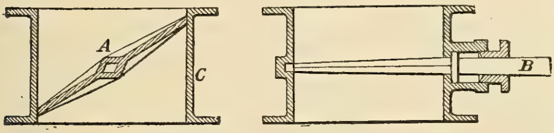


Fig. 279.—Throttle Valve.
A, Throttle valve. B, Spindle for do. C, Chest.

The *blow-through valve* is a common spindle one, guided at the bottom through a hole in the centre boss cast along with the seating, with a single feather; or the valve may be of the three-feather type, turned to the inside diameter of the seating. The former has a long spindle at the top, which passes through a stuffing box on the cover of the valve box. This spindle is fitted with a slot crosshead for the lifting arm to pass through, with a lever and rod passing along to the starting platform. Some makers have used a small slide valve, with steam and exhaust ports placed on the top of the cylinder, with steam passages and valve chest cast in brass. This valve is worked by hand off the platform, and can be used for blowing through, or even turning the engines gently, in which respect it serves as a means of starting the machinery independently of the main slide valve—a great desideratum in large-powered engines. Plain plug valves may be conveniently used for the blow through, but it is not advisable to adopt them for heavy engines. The plug should be packed with hemp at the top, having a suitable

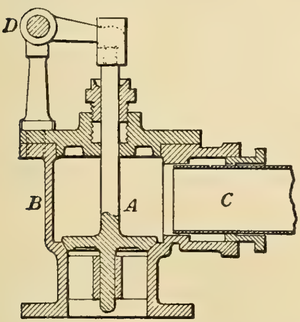


Fig. 280.—Blow-through Valve.
A, Valve and spindle. B, Chest. C, Stuffing box and gland. D, Lifting lever.

packing gland, and the bottom or small end of the plug is merely fitted, and ground into the seating, which is cast solid at the end; by this means no leakage can occur except at the top, which is made steam-tight by the packing gland.

The *escape* or *relief valve,* fitted to the bottom of the cylinder cover and to the front end of the cylinder, is intended to allow the escape of the water which finds its way into the cylinder from priming and condensation of the steam. It consists of a disc valve with a spring fitted to the top, screwed down sufficiently tight to resist the steam pressure acting on the internal area of the valve. The valve can only be opened, and the water which is not compressible ejected, by the piston striking against the water, and forcibly lifting the valve, compressing the spring, which again reacts when the cylinder is free of water. The valve should be inclosed in a light dome, with a hole at the bottom side for allowing the hot water to escape downwards into the bilges. In other examples a dash or splash plate is cast along with the valves, when placed horizontally and vertically; the plate being of a curved shape, the water escaping all round the valve is returned or thrown back again, and so prevented from being scattered about the engine room, and scalding the engineers or those in attendance. The spring is usually screwed down with a crosshead, through which the valve spindle passes loosely through a hole bored in the centre. At each end of the crosshead is a column, secured to the valve seat at one end, and the other end screwed, passing through a hole in the crosshead, and fitted with nuts above and below. The spring is placed around the spindle, between the valve and the crosshead, which by means of the nuts is screwed up carefully, compressing the valve to a little above the working pressure of the steam in the cylinders, which can be easily adjusted when the engines are started, and then the nuts below the crosshead can be screwed hard up; in this way the valve is guided at the top through the crosshead, and at the bottom the spindle passes through the hole in the central boss cast along with the valve seating. Some engineers dispense with the movable crosshead, using merely a bow or fixed crosshead of wrought iron

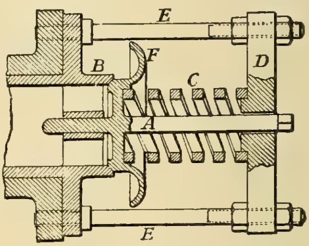


Fig. 281.—Relief Valve with movable Crosshead.

A. Valve and spindle. B, Valve seat. C, Spring. D, Crosshead. E E, Columns. F, Baffle piece.

secured to the seating with nuts, and a central boss at the top, for the reception of a screwed stud for tightening up or compressing the spring; one cap being cast along with the valve for the spring to rest on, and another cap at the top of the spring on which the screw

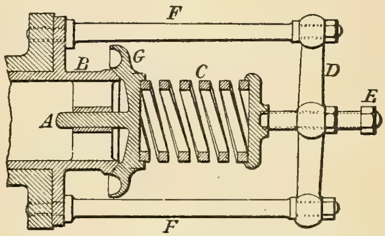


Fig. 282.—Relief Valve with fixed Crosshead.

A, Valve. B, Valve seat. C, Spring. D, Cross-head. E, Set screw. F F, Columns. G, Baffle piece.

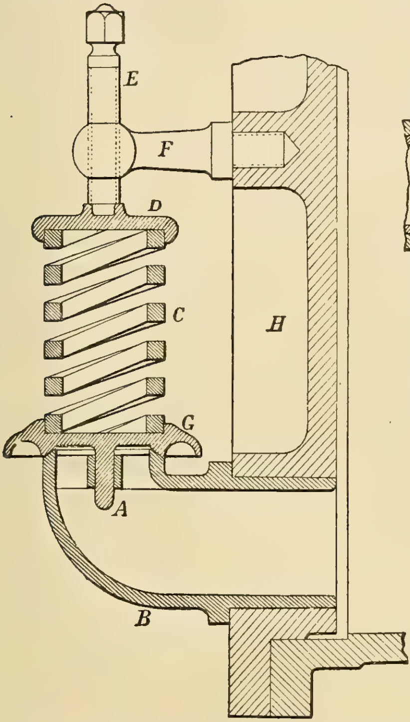


Fig. 283.—Relief Valve with Stud on Cylinder Cover.

A, Valve. B, Valve seat. C, Spring. D, Cap. E, Set screw. F, Stud. G, Baffle piece. H, Cylinder cover.

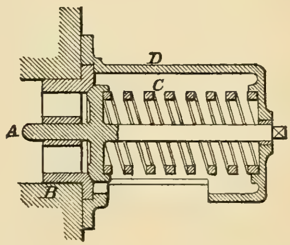


Fig. 284.—Relief Valve with Dome.

A, Valve and spindle. B, Valve seat. C, Spring. D, Baffle dome.

for compressing the spring bears: in this arrangement the valve is guided by the spindle passing through the seating. A very simple form of this description dispenses with the wrought-iron bow, a stud being screwed into the cylinder cover and end, through which the screw for tightening up the spring passes; while in other forms the dome fitted over the spring for protecting it from being injured, as well as for preventing the water flying about the engine room, is fitted with a boss at the top, through which the tightening-up screw passes, the dome being bolted to the covers and end with stud bolts. Many prefer a fixed pressure on the relief valve, but,

on the whole, we think it should be fitted with set screws, to adjust the pressure against the valve at any time to suit the reduction in steam pressure that may be considered advisable after the boiler has worked for a lengthened period. Some makers have fitted an additional valve opening downwards, seated on the main relief valve, and opened by hand, while another valve of india rubber is placed on the top of the main relief one, so that when the additional valve is opened, in the event of violent priming at the return stroke of the piston, the disc of india rubber, or metal valve if so fitted, closes, and does not impair the vacuum. This is a complicated arrangement, not in general use; and the same object is attained by fitting a plug valve at the bottom of each end of the cylinder, worked simultaneously from the starting platform, and which can be opened when violent priming occurs, or in the act of blowing through before starting the engine,—in the same way as the plug valves in the locomotive engine cylinder, which are left open for a considerable time to blow out thoroughly all the water from the cylinders. Some first-class engineers consider that greater safety would be insured by dispensing with the springs for holding down the relief valves, and this seems a step in the right direction; for when valves are so arranged that they are held down simply by the steam, and have the means of blowing all the water back again into the steam pipes, and collecting it in a suitable separator, we secure two advantages, namely, that the valves are not so liable to stick or get damaged, and that the hot water does not fly about, but is received into the separator, which can be run off occasionally. For this purpose, double-beat valves, giving a large circumferential area for the water to escape, or common spindle valves, are fitted to the top of the cylinder, in valve chests, which communicate by pipes with the cylinder on the bottom of the valve and the steam pipe on the top of the valve; the steam pressure above the valve being greater than that in the cylinder, the valves are of course held down by the difference of pressure, and the water is ejected as in ordinary arrangements, with this difference that it is collected in a vessel for the purpose, instead of finding its way into the bilges.

Lubricators.—Grease cups are fitted to the steam ports at the front and back of the cylinder, for lubricating the valve and piston, the lubricant being drawn in with the vacuum. These cups should be fitted in connection with a plug valve having a screwed part at

the top, to suit the screw of the indicator, with a pipe connected between the plug valves, so that an indicated card may be taken from the front end and back of the cylinder without shifting the instrument. The pipe between the plug valves should be fitted with an additional valve, for cutting off the communication when it is desirable to take a card from the front end, and *vice versa.* The liquid tallow is poured into the cup, and flows through a hole into the hollow plug; the valve is then turned by hand, bringing the hole into communication with a small hole on the opposite side leading into the port, and the oil is drawn into the cylinder by the vacuum. Sometimes a plug tap is fitted into the tallow cup, and opened and shut by hand; but this operation requires some care, as it is evident that it must not be opened until the vacuum is formed, or the tallow would be blown out of the cup. The attendant must therefore watch the motion of the engine, and shut off the communication with the cylinder before the steam is again admitted, so as to allow the tallow to be drawn into the cylinder with the vacuum—an operation requiring some dexterity, with the piston doing sixty strokes or so per minute. It is therefore preferable to use the hollow plug valve, as described above.

We now come to consider the *piston* for the various forms of horizontal marine engines. In the construction of this part the main point to be studied is to provide ample surface for wear. The thrust is imparted more directly on the piston in the single-trunk type than where there is a trunk at each end of the cylinder. In the latter arrangement the trunks form a hollow support for the piston, while the thrust of the connecting rod is taken on the bushes and packing glands in the ends of the cylinder, and the rubbing surface of the piston can be made much less than for any other class of horizontal engine. While other pistons must have a broad surface for wear, the packing rings for the double-trunk system have in some instances merely slight steel or brass hoops for making them steam-tight. Pistons for two or more piston rods on the return connecting-rod principle require less area for the rubbing surface than those for direct-action single piston-rod engines, the former being partly balanced by the long rods and heavy cross-heads, the stuffing boxes serving as a fulcrum by which the weight of the piston is partly taken off the cylinder surface, and this tends to prevent them wearing so rapidly as in the direct-acting type, although the diameter of the piston rod in the latter is increased to

gain more surface in the glands, and by the increased weight of the rod and its adjuncts to relieve the piston rubbing surface. The total rubbing surface or depth of the piston, for double trunks, may be taken at one-eleventh of the diameter of the cylinder; for double piston-rod engines on the return connecting principle, one-sixth; for single piston-rod and single-trunk arrangements, one-fifth: this depth being the breadth over the surface in contact with the cylinder. Most pistons have projecting rings cast along with the junk ring, and some have also projecting rings cast along with the main body of the piston—both having in view the equalization of the junk ring and end surface in connection with the main packing ring; this is necessary, as the rubbing surfaces on the junk and back ring have the weight of the piston, and in some instances the thrust of the connecting rod, to sustain, while the packing ring has not so much duty to perform. In order to make the junk ring and other surfaces to bear more equally, and to keep the piston central with the cylinder, two pieces of cast iron are placed on the under side, between the packing ring and the main body of the piston, pitched about one-fifth of the diameter of the piston apart; in this

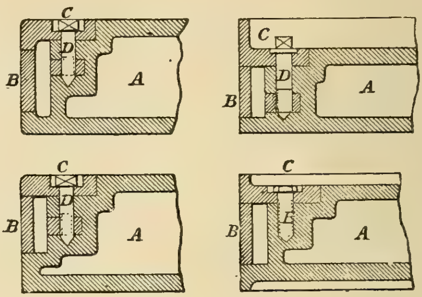


Fig. 285.—Piston Rings.

A A, Pistons. B B, Packing rings. C C, Junk rings. D D, Bolts with recessed nuts. E, Bolt with hole tapped in the body of the piston.

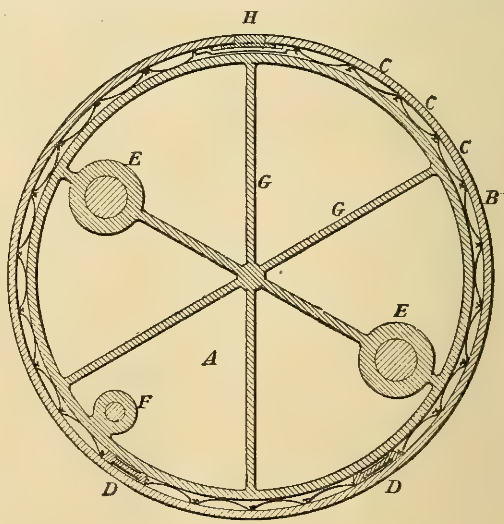


Fig. 286.—Piston.

A, Piston. B, Packing ring. C C C, Springs. D D, Cast-iron pieces. E E, Bosses for piston rods. F, Boss for air-pump rod. G G, Ribs to strengthen the body of the piston. H, Tongue at division.

way the weight of the piston is transmitted through rigid blocks to the packing ring, which bears on the internal surface of the cylinder. Short springs of a bow shape are placed all round the packing ring, to keep it well up to the cylinder surface. In some cases these springs are of a U shape, let into recesses in the body of the piston. The main body of the piston is strengthened with ribs radiating from the centre, and has the necessary bosses, which are bored out for the reception of the piston and air-pump rods; the holes are sometimes tapered to receive the ends of the rods, and in other examples they are quite parallel; in the former case, the piston rod is screwed tightly against the cone, and in the latter against a shoulder left on the rod itself. Holes are cast in the body of the piston for the purpose of extracting the cores; these are accurately bored out with a slight cone, and plugged up with cast-iron plugs, having a thin coating of red lead to make the joint perfectly steam-tight. They are further secured by boring holes on the circumferential line of the joint, which are tapped for the reception of brass or wrought-iron screws, firmly screwed in, one-half of the screw being in the body of the piston and the other half in the plug; these screws are cut off flush with the surface of the casting. The junk ring is held down by bolts screwed into the cast-iron piston, or brass or wrought-iron nuts are fitted, recessed into it, having a thickness of metal all round; the bolts are kept from turning by a screwed stud recessed in the head, and tapped into the junk ring. The ring is accurately turned, as also the surfaces bearing on the piston and the spring ring, which are then scraped to a true surface, and made perfectly steam-tight. After the packing ring is turned, an oblong hole is cut out at the centre at that part where the ring is cut through, and a brass piece with a flange all round is fitted into the hole, filling it up, while the flanges make the spring joint steam-tight; the end of the brass filling-in piece is secured to the packing ring at one end with screwed studs, and a wrought-iron bridle is placed over the tongue, and secured likewise at one end to the packing ring. The object of this arrangement

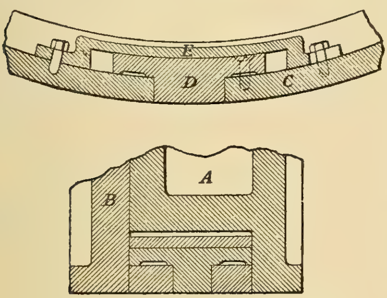


Fig. 287.—Block Piece for Piston Ring.
A, Piston. B, Junk ring. C, Packing ring. D, Tongue. E, Bridle.

is to compress the packing ring, by the insertion of a wedge between the tongue piece at the fast end and the bridle at the loose end, so that when the wedge is driven in between the two the packing ring is drawn together, and can be readily placed in the piston when in the cylinder; the cotter is then drawn out, and the packing ring expands to its original size, and fills the cylinder somewhat tightly. The projections left on the junk rings and the body of the piston must have recessed parts in the cover and end of the cylinder, with sufficient clearance at the end and round the projections; and it is advisable to leave recessed parts at both ends of the cylinder, making the part bored out somewhat shorter than the actual stroke of the piston, so that the rubbing surface travels over it at each end, and prevents a groove forming in the cylinder that would eventually prove destructive to the engine, in the event of the connecting rods requiring lining up in the brasses, by causing the piston to strike hard against the projections. Sometimes the piston for direct-acting single piston-rod engines is dished out or formed of a curved shape, with the view of getting more room for the crosshead, the gland for the rod being recessed into the end of the cylinder. This is the only advantage to be derived from this plan, and it is but rarely adopted. The fittings of such pistons are identical with those for the plain-ended arrangement. When annular cylinders are adopted for high and low pressure combined engines, the small piston for the high-pressure cylinder is similar to an ordinary one, but the piston for the annular cylinder must have two packing rings, the outside ring bearing on the cylinder surface, as in ordinary arrangements, but the internal packing ring bears on the inside diameter of the ring, the ring being pressed up against the barrel of the high-pressure cylinder with strong steel springs. These pistons are generally connected to the crosshead by a central piston rod for the high-pressure cylinder, and two side ones for the low-pressure cylinder, with one crosshead common to both. There must be block pieces fitted between each packing ring and the body of the pistons, to keep them all fair with one another. The packing rings of all pistons are generally made thicker at the bottom where these blocks are fitted, and thinner at the top where the ring is cut; this is necessary, as in all horizontal arrangements the severest strains and wear are undoubtedly at the bottom of the piston.

As bearing on this subject the following extracts are from a

paper on "Pistons," read by Mr. James Howden before the Institution of Engineers and Shipbuilders in Scotland, session 1880–81:—"Absolute steam-tightness in a piston at work very seldom occurs. It is much more difficult to secure than is generally supposed. Probably steam-tightness has never existed in any piston with a single packing ring after it has worked a short time, even though the piston has been perfectly steam-tight at first starting. On removing the junk ring of any such piston after it has worked for some time, evidences of steam having passed between the faces of the packing ring and junk ring or piston flange into the interior space are quite apparent. The scraped or ground faces are in places dull and steam worn, and if oil or grease has been used to lubricate the cylinder, grease and dirt will be found in the space inside of the packing ring.

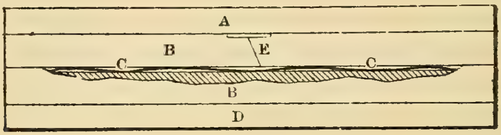
"In pistons with double packing rings leakage over their end faces is sought to be overcome by a pressure endwise from a spring which presses the packing rings at same time outwards towards the walls of the cylinder. This causes undue friction and wear of the cylinder and packing rings; and where there is much wear there will soon necessarily be leakage through the packing rings and interior of the piston. The dirt and grease often so plentifully found inside the packing rings, show that steam has been passing about as freely to the inside of the piston as into the cylinder itself.

"The element of friction is an important one, and a piston at once steam-tight and practically frictionless possesses a value which it would be difficult to overestimate. There cannot, of course, be an entire absence of friction, but it may be reduced to the least possible extent. The piston of a well-made indicator is an example of a piston steam-tight under any usual pressure, and practically frictionless. It works without any pressure outwards against the walls of the cylinder. In pistons with packing rings and compensating springs, one of their greatest defects is the universal excess of pressure outwards against the cylinder. It is generally supposed that when a cylinder is found smooth and polished, that the piston is working with very little friction. This is often a delusive inference, for in a well-lubricated cylinder the packing rings, if bearing fairly all round, will make a smooth skin on the cylinder, even under a strong pressure against it."

The author, in describing a new form of piston, the invention of Mr. Wm. Rowan of Belfast, states:—"This piston is, however,

distinguished from all other pistons of this class by effecting the endwise and outward pressures by separate springs, each exactly suited for the work they have to perform. As I have shown, the pressure of the packing rings endwise should be strong, and their pressure outward against the cylinder light, or exactly the reverse of what occurs in all other double packing ring pistons.

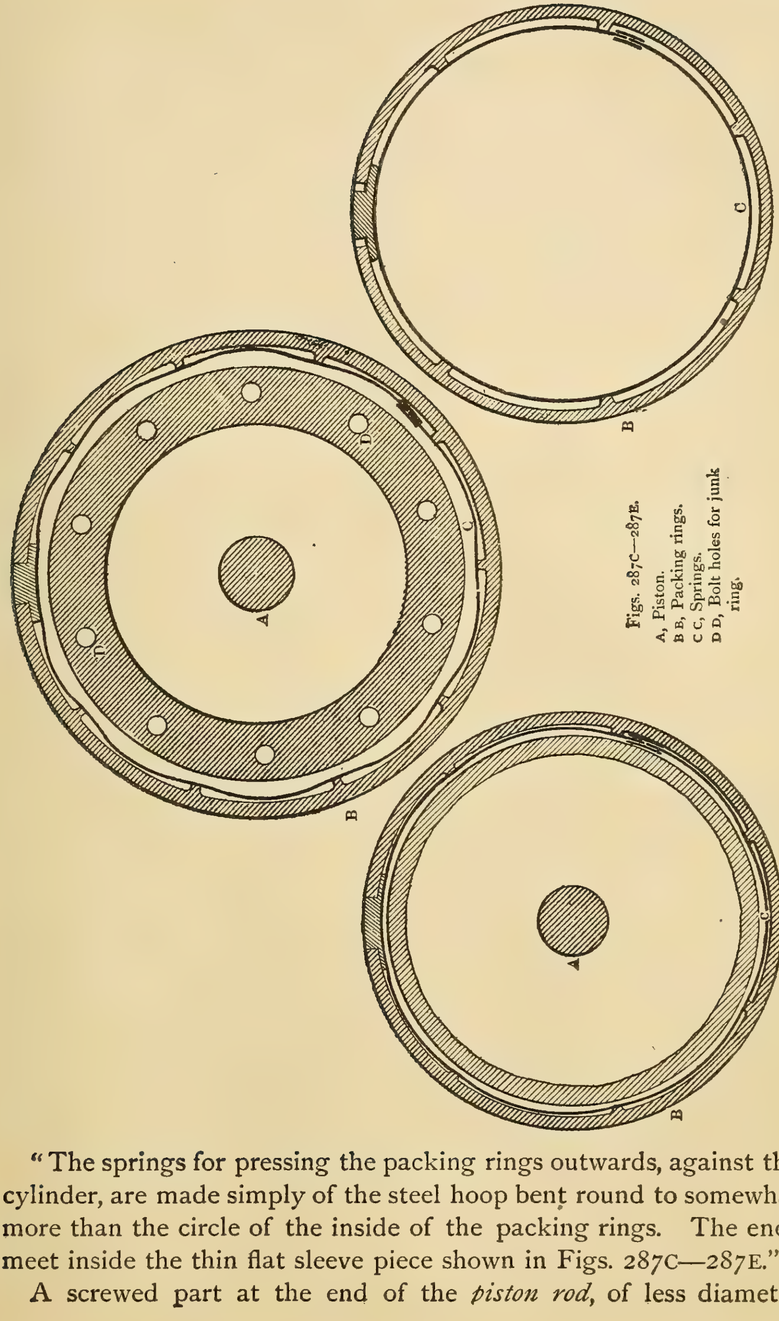
"The springs are extremely simple in their character and construction. They are made from light hoop spring steel, varying in breadth and thickness to suit the diameter of the piston. Breadths from ½ inch to 2 inches, and thicknesses from $\frac{1}{16}$ inch to $\frac{3}{16}$ inch, will serve for pistons from 1 to 6 feet in diameter. To one seeing them for the first time these springs look quite inadequate to accomplish the ends proposed. It is surprising to see a spring of



Figs. 287A, 287B.—A, Junk ring. B B, Packing rings. C, Spring. D, Flange on piston. E, Part where the packing rings are cut.

a few pounds weight in a large piston accomplishing an effect to obtain which in other pistons continuous springs weighing several hundredweights are used.

"The spring for pressing the packing rings against the junk ring and piston flange is bent round on its flat to the required diameter, and may have projections on either side alternately at definite distances apart, or the projections may be similarly placed on the contiguous faces of the packing rings, between which these springs are placed. The preferable mode, however, and that usually adopted, is to have the projections on the spring itself in the form of waves, as shown in Figs. 287A and 287B, and where they are shown in position between the two packing rings. It is found that springs made in this manner to definite proportions of height and length of waves, now fully ascertained for all dimensions, can be made to give an almost unlimited pressure when screwed to required position, and the elasticity remains good for years.



Figs. 287C—287E.
A, Piston.
B B, Packing rings.
C C, Springs.
D D, Bolt holes for junk ring.

"The springs for pressing the packing rings outwards, against the cylinder, are made simply of the steel hoop bent round to somewhat more than the circle of the inside of the packing rings. The ends meet inside the thin flat sleeve piece shown in Figs. 287C—287E."

A screwed part at the end of the *piston rod*, of less diameter

than the main part of the rod, receives a large nut, by which the piston rod is secured to the piston. The part of the rod passing through the piston is of increased diameter and cone-shaped, this cone is drawn through a corresponding hole bored in the piston, and held firmly by the large nut at the end, which is kept from turning backwards by a split pin bearing on it, and passing through a hole bored in the end of the rod. This cone in some examples is no larger than the rod at the one end, and is reduced at the end nearest the nut, in which case no raised part is required to be forged on the rod; a collar, however, is sometimes left to screw the piston against. Some makers prefer having that part of the rod which

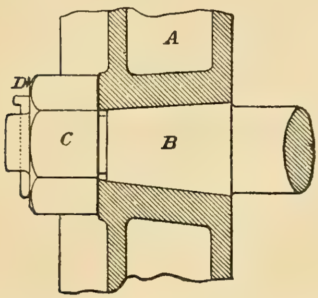


Fig. 288.—Tapered Rod and Nut for Piston.

A, Piston. B, Taper on rod. C, Nut. D, Split pin.

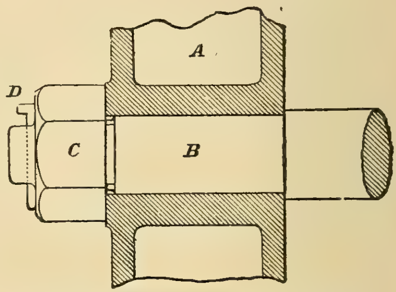


Fig. 289.—Parallel Rod and Nut for Piston.

A, Piston. B, Parallel part on the piston rod. C, Nut. D, Split pin.

passes through the piston quite parallel, or nearly so, with a shoulder formed by the reduction of diameter, against which the piston is screwed. The screw is generally of a V form, rounded at the top and bottom of the thread; others are cut square, but the V thread is preferable. The nut in most examples projects from the body of the piston, and bears on a turned raised part formed on the casting; in others it is recessed into the piston, and in others again it is flush with it, or a small projection of the nut is left, so that it can be turned round with an ordinary spanner. When the rod passes through a crosshead, its end is turned down quite parallel and secured to the crosshead with a nut, in the same way as for the piston. Some engineers place a jam nut on the back of the main one, with split pins passing through both nuts, thus making a very secure fastening. These lock nuts should be placed on all the parts which are liable to shake loose, more especially for direct-action engines, as the speed at which these are driven is liable to

loosen the parts if not properly secured. For direct-acting single piston-rod arrangements a T-shaped piece is formed on the end for taking the crosshead, or brasses, which are secured to the rod by two bolts passing through the T piece, brasses, and cap; the nuts being secured at the ends of the bolts with split pins. The nut can be fitted with a washer with pin let into the cap, and a small set screw placed at the top of the one and the bottom side of the other, passing through the washer and bearing in a hollow turned in the reduced part of the nut. With the T form there must not be any raised part on the piston rod at the piston end, so as to allow the glands and bushes to pass freely along; these must of course be placed on the rod before it is secured to the piston, for it is not advisable, under any circumstances, to cut the glands in two, as some prefer doing in oscillating arrangements.

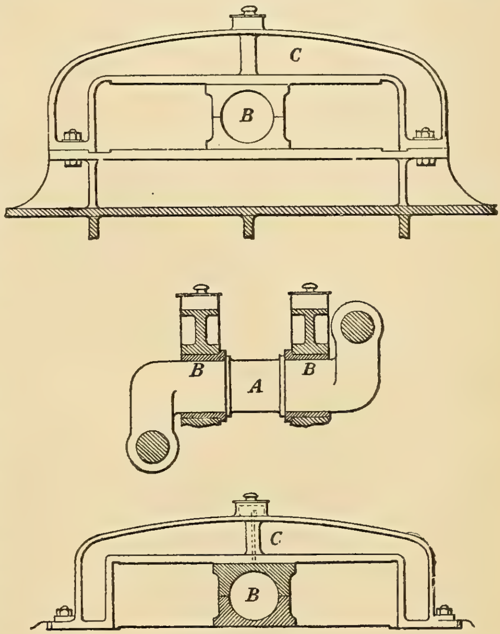


Fig. 290.—Crosshead Gudgeon and Motion Bars.
A, Gudgeon. B B, Slide blocks. C C, Motion bars.

The *guides and crosshead* for double piston-rod engines, on the return connecting-rod principle, are best arranged with two guides or motion bars, one on each side of the connecting rod. By this arrangement the crosshead is well supported at the ends, and the strain on the guide bars is in a direct line with the centre line of the cylinder. The crosshead is a circular forging, with arms forged on for taking the piston rods. In some cases it is turned quite parallel between the arms, these being forged on at right angles to the main part of the crosshead; in others a collar is formed on each side between the connecting-rod brasses and the guide blocks. When the arms are forged on at an angle with the crosshead, it is advisable to make the connecting-rod bearing of a larger diameter,

finishing up the arms quite square, and fitting the sliding blocks of brass to them. When this part of the crosshead is turned, the sliding blocks are bored out, and are held in position with a side flange; the blocks are planed at the top and bottom. In some instances cast-iron blocks have been used, lined on the rubbing surfaces with white metal. The motion bars are of cast iron, the bottom one is cast along with the condenser, and the top one, of an I section, is bolted down at each end with one large bolt, passing down through the vertical distance pieces cast along with the bar; or two smaller bolts passing through flanges at the bottom may be conveniently adopted, in which case the bottom motion bar is generally raised up from the condenser casting, having strengthening ribs cast along with it. One or more oil cups, provided with covers and wick siphon pipes, should be cast on the top of the guide bar, to lubricate the sliding surfaces. The crosshead in other arrangements is let into the pillow-block pieces (fitted with caps and bolts), which are cast along with a T piece at the bottom, placed centrally, and which is fitted with a separate brass casting, having clips at the end to take the sliding strain. This guide block has a large flat surface at the bottom, but the surface at the top is not of so large an area, owing to the thrust of the connecting rod being neutralized by the weight of the crosshead and adjuncts. Some engineers, indeed, have left a small space between the top surfaces, thus showing clearly that the top thrust is but little felt. The guide bar is of a trough section, and is bolted down to the condenser casting, having means of adjusting it to suit the wear of the brass sliding piece. The lubrication of the parts is effected by means of an open oil well at each end, which is kept constantly full; the bottom sliding piece travels a somewhat greater length than the surface provided on the trough guide plate, consequently its bottom skims the oil in the receivers at each end, thus keeping the guide plate thoroughly lubricated. All these arrangements of crossheads are suited for plain connecting rods; some builders, however, adopt forked connecting rods, having the crosshead, or rather the pin for the connecting rod, fixed firmly on the rod, working in a single pillow block and guide piece, provided with caps and brasses, as in the previous example. The crosshead for taking the piston rods can by this means be forged and finished quite flat, and it is bolted to the guide block with the two large bolts taking the cap and securing the brasses for the connecting-rod pin.

This arrangement of crosshead is certainly preferable to those having the arms forged on at an angle from the connecting rod bearing, as it assumes a more direct form of beam, loaded at the end with the steam pressure communicated from the piston through the piston rods, taken centrally with the connecting rod, which in its turn acts on the arms of the cranked shaft, the bearing of which is subjected to torsional stress.

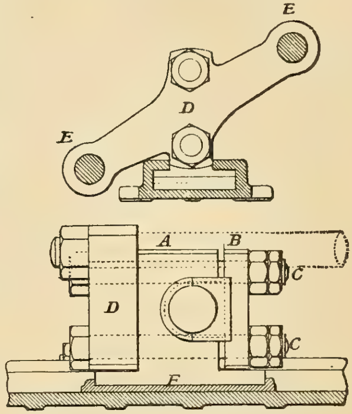


Fig. 291.—Crosshead for Piston Rods.

A, Pillow block on crosshead fitted with brasses. B, Cap. C C, Bolts and nuts. D, Crosshead. E E, Eyes for the piston rods. F, Brass sliding piece.

We have now to consider the connection between the piston rod and the connecting rod for direct-action single piston-rod arrangements. The brasses for taking the forked end of the connecting rod are cast in two halves, on each of which is cast a bottom guide piece; they are grooved out for the reception of a wedge plate, the bottom of which is parallel with the centre line of the rod, but of a wedge shape on its upper surface, which bears on the brass pieces, and which is secured at one end, but having the means of adjusting

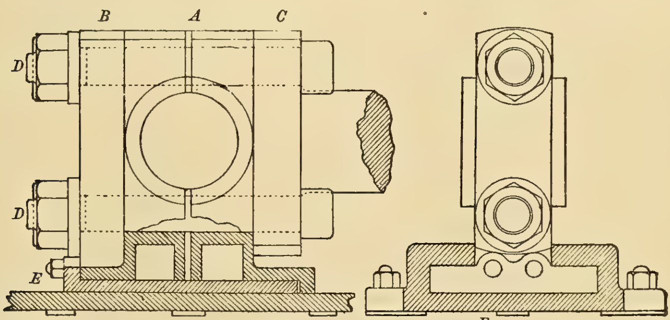


Fig. 292.—Crosshead for Single Piston Rod.

A, Brass crosshead. B, Cap. C, T piece forged on the piston rod. D D, Bolts and nuts. E, Adjustable plate. F, Guide for crosshead.

the sliding brass against the bottom guide plate, as in the examples already described. The piston rod has a T piece for attachment to these brasses, and at the connecting-rod end a cap is fitted; these are all held together by two large bolts passing through the T piece,

brasses, and cap. This is a neat form of connection; whether the brasses have a plain exterior or are cut out in the pattern, the bottom part is generally cored out to save weight and metal. For trunk engines of the single class the brasses are placed in a pillow block, cast along with the piston, and two bolts pass through the piston for securing the cap. This arrangement is adopted for forked connecting rods; but for single connecting rod ends, both in single-trunk and double-trunk arrangements, the pillow block and brasses are dispensed with, and a crosshead of wrought iron is substituted, with bosses forged on the end, through which it is securely bolted to the trunk. In single-trunk engines raised bosses are cast on the piston, and accurately faced for fitting against, the bolts passing through the piston, and having their heads covered with a plate let into the piston, which prevents the steam escaping through the trunk into the atmosphere; while in the double-trunk engine the crosshead is secured by bolts which pass through snugs cast along with the trunk, and do not require to be made steam-tight, as in the preceding case. The snugs should be strengthened with a deep feather, so as to take the thrust and pull which is transmitted on all connecting-rod attachments.

The most approved form of *connecting rod* between the cross-

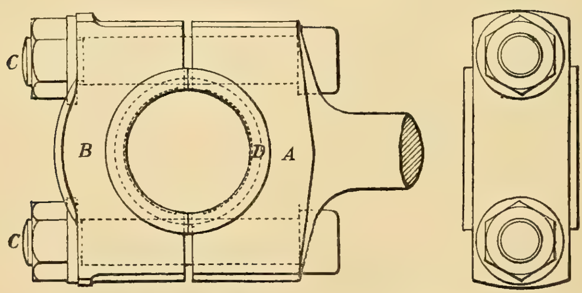


Fig. 293.—Connecting-rod End for Cranked Shaft.

A, End forged on the piston rod. B, Cap. C C, Bolts and nuts. D, Brasses.

head and cranked shaft is that with solid ends forged on, slotted out for the reception of the brasses, with caps of wrought iron secured by two large bolts. The part for taking the brasses can be bored out, the bedding forming a true circle; the ends and cap are forged, turned, and finished entire, with holes bored for the reception of the bolts, which are so spaced that part of the brasses require to be scooped out, which prevents them turning round in

their seats. After the end is finished it is slotted across the middle, the part slotted off forming the cap; the brasses have the usual flanges all round, and are entirely finished in the turning lathe. The bolts have solid heads, with part of the nuts recessed into the cap, and a set screw passes through the side of the head, pressing against the nut to prevent it becoming loose; the bolts are secured in like manner: these precautions being necessary with high-speed

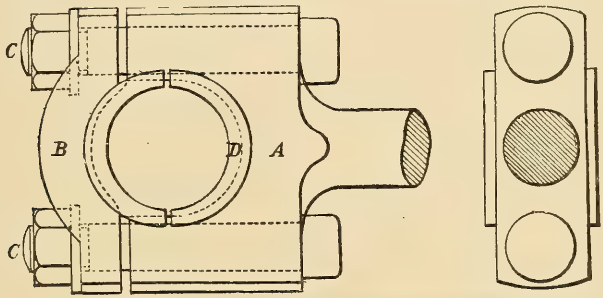


Fig. 294.—Connecting-rod End for Cranked Shaft.

A, End forged on the piston rod. B, Cap. C C, Bolts and nuts. D, Brasses.

engines. Some engineers prefer to have a flat part left for the sides of the brasses, made deep enough to take a part of the top brass, with a cap of sufficient depth to suit the requirements; the heads and nuts of the bolts are not generally recessed into the block and cap, but the nuts are turned down, leaving a hollow part, and a washer fitted with a pin in the cap, with a set screw bearing in the groove cut out in the nut to prevent it shaking loose. In some examples both of the ends are forged on in one block; and others have forked ends to suit the crosshead adopted, having a pin securely fastened through holes bored out in the forked ends, with a collar at one end and a pin at the other end securely rivetted in. Other forms of connecting rods have T pieces forged on the ends, with brass distance blocks between the T piece and the cap, bolted together with two bolts. These blocks are lined with white metal, and are bored out to suit the pin on the cranked shaft; the end for the crosshead does not require white metal let in. In some cases the blocks are made quite plain and flat on the sides, in others the pattern is cut out to save metal. The bolts for securing the brasses are fitted with nuts and washers, having set screws for preventing the nuts working loose. Sometimes a round boss is left on the bottom brass, having a corresponding hole in the T piece; this

helps to take the side strain off the bolts, but the generality of makers leave these surfaces quite plain. When the bottom end of the connecting rod is connected to a journal inside of a trunk, it is necessary that the brasses can be tightened up from the outside, and for this purpose the eye of the rod is forged on solid, and bored and slotted out for the brasses; the rod is then bored out for nearly its entire length, for the reception of an inside steel bar, which is fitted at the top with a cotter for tightening up the rod against a steel plate let into the top brass, the bottom brass having a projection cast on, which fits into the central hole in the connecting rod. This is a neat arrangement, and cannot be dispensed with when the brasses work in a crosshead held quite rigid.

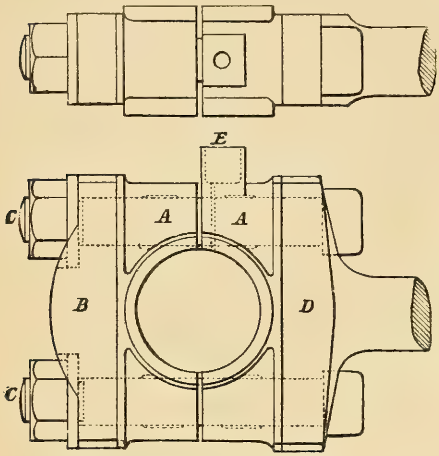


Fig. 295.—Connecting-rod End for Cranked Shaft.
A A, Brass ends. B, Cap. C C, Bolts and nuts. D, T piece forged on the piston rod. E, Oil cup.

The old form of connecting rod, with straps, jibs, and keys, may in some instances be beneficially adopted, more especially for the crosshead for double piston-rod return connecting-rod engines; in this arrangement, having the keys passing through a slotted-out part left in the broad rubbing surface, with a groove formed in the condenser casting for the end of the key to travel backward and forward in, the distance from the centre of the journal of the crosshead to the plate on which the block slides can be greatly reduced, which is a somewhat important consideration. A very simple form of connecting rod has half brasses

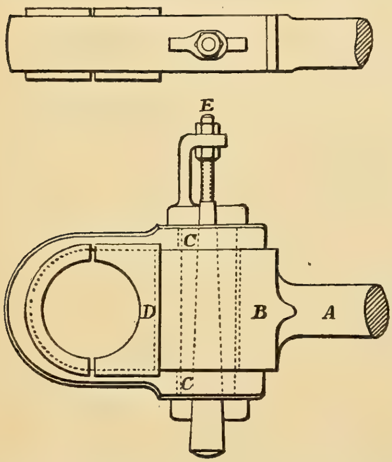


Fig. 296.—Connecting-rod End for Cranked Shaft,
A, Rod. B, Butt. C C, Strap. D, Brasses.
E, Jibs and cotters.

at the top and bottom, with a small rod on each side, on which are left collars for the bottom part or inside brasses to bear against, while the two outside brasses are bolted hard up against the inside ones, with a screwed part on the ends of the rods having nuts and washers: these rods therefore act as the main connecting rod and tightening-up bolts. This plan, however, has not been much adopted.

The next detail to consider is the *cranked shaft*—a term adopted to distinguish between cranks forged in one piece with the shaft, and plain ones having cranks shrunk on. The crank arms are forged on solid at right angles to each other, they are then bored across and slotted out for the part between the jaws, leaving a part for the crank pin, which is turned out in the turning lathes or cutting-out machines used for that purpose. There are three main bearings, one on each side of the cranks at the outside and one central bearing between them. When the distance between the cylinders is great, the cranked shaft is separated at the centre between the cranks, having solid discs forged on, secured with bolts and nuts, and a cross key for taking the sheering strain off the bolts: in this arrangement two central bearings are provided, instead of one, as when both cranks are forged on entire. The end parts of the crank arms are often finished in the turning lathe, but some examples have the circular form; the former, however, is the better plan when counter weights are strapped on for balancing the weight of the crank arms. These straps are quite flat, except where they pass through the cast-iron balancing piece, where they are rounded. The balancing piece is secured with nuts, let into the block at the extreme end, and joggled into the arms at the crank end; the end of the strap should have a round pin rivetted in, with a corresponding hole bored on the crank end, which tends to prevent the strap moving sideways. Some makers leave a joggle on each side of the strap by planing out the sides of the crank arm, which makes

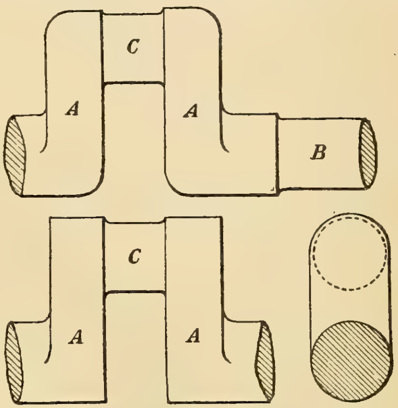


Fig. 297.—Cranked Shaft.
A A, Cranked shaft. B, Main bearing. C, Crank pin.

a first-class piece of work, effectually preventing these balance weights moving sideways. The crank arms in some cases taper from the shaft to the crank-pin bearing, in others they are left parallel; and when other modes of balancing the cranks and connecting rods are adopted, the corners of the cranks can be finished to a bold radius, by which part of the weight requiring balancing is removed. The journals for the cranked shaft, and indeed all journals, should be finished with the tool in the lathe; the use of emery to get up a smooth face is a practice long ago exploded, and rightly so, as many journals and bearings have been torn and rutted up by the fine particles of emery indented in the iron. All the collars should be turned with a bold radius, for when they are left square it is generally here that the shaft gives way after long use. As the strain imparted from the thrust and pull, passing from the piston through the rods, is both rapid and severe, this accident may occur with the best arrangements; it is therefore always advisable to have a spare cranked shaft stowed on board the ship.

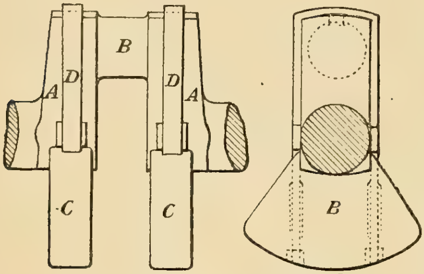


Fig. 298.—Balance and Cranked Shaft.

A A, Cranked shaft. B, Crank pin. C C, Balances. D D, Straps.

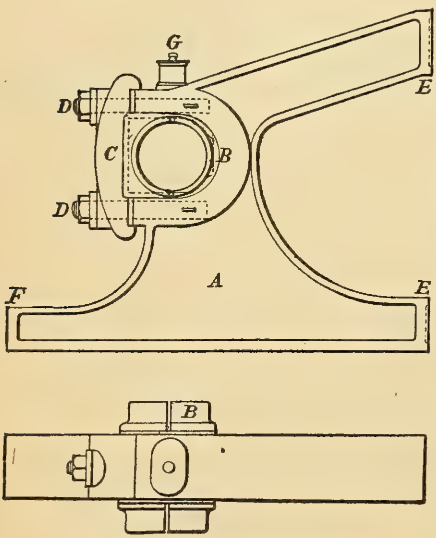


Fig. 299.—Main Framing of I Section.

A, Main frame. B, Brasses. C, Cap. D D, Cotter bolts and nuts. E E, Flanges for bolting to cylinder. F, Flange for bolting to condenser. G, Oil cup.

What are called built shafts are those in which the crank and crank pins are shrunk on. A fire, generally of wood, is lighted round the cranks, and when sufficient expansion has taken place the parts are slipped into position. The crank on cooling down grips the shaft and pin tightly.

Fig. 298A shows the crank shaft of the screw steamer *Arizona*. It is built up of five pieces. Of these four are made of hammered and rolled scrap iron, the fifth, or crank pin, being made of steel. The diameter is 22½ inches.

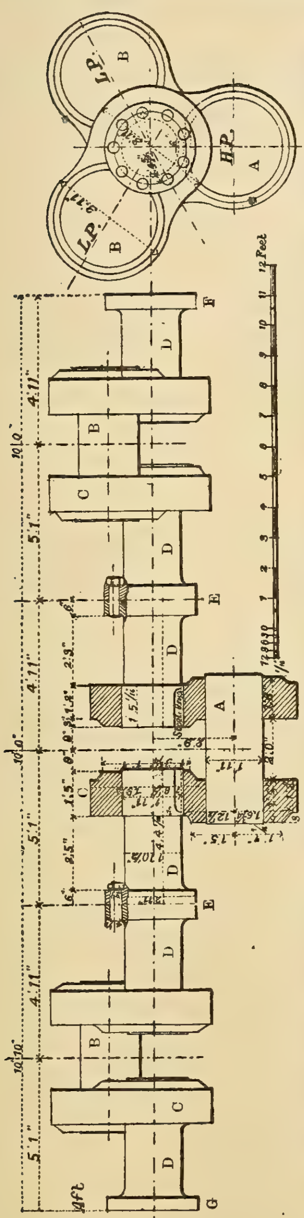


Fig. 298A.—Crank Shaft of Screw Steamer *Arizona*. A, Crank pin for high-pressure cylinder. B B, Crank pins for low-pressure cylinders. C C, Cranks. D D, Bearings. E E, Couplings on which eccentrics are placed. F, Disc on which eccentrics are placed. G, Coupling on which turning gear is placed.

The immense power of engines in some of the recently launched ocean steamships for the Atlantic service necessitates correspondingly heavy and strong machinery; thus the crank shaft of the *Servia*, *City of Rome*, and *Alaska* are about 25 inches in diameter; those of the *Servia* and *Alaska* are solid, whilst that of the *City of Rome* is hollow. This shaft is of steel and made by Sir J. Whitworth's process, the steel being known as fluid compressed, this method being adopted to insure uniformity in structure. The process consists in first of all casting the steel in a mould having a core; thereafter, and while still fluid, the casting is subjected to an intense hydraulic pressure, which forces the air and gaseous matters out of the fluid mass. After solidifying the metal is reheated and forged down to a length suitable for the purpose for which it is to be applied. A stronger shaft for the same weight of metal is thus obtained.

The *main framing* (Fig. 299) on which the pillow blocks are cast for sustaining the cranked shaft may be regarded as the backbone of horizontal marine engines. It is subjected to tensional, compressive, and twisting strain, and must therefore be made of great strength. Some makers adopt the I section, others the +,

while some consider the box form preferable; and all these forms are successfully carried out in practice. Strength is the main thing to be looked to; but the open form of framing has the advantage of giving more convenient access to the various glands. The frame is firmly bolted to the cylinder at the top and bottom, and also to a flange carried along from the cylinder to the condenser. This flange is

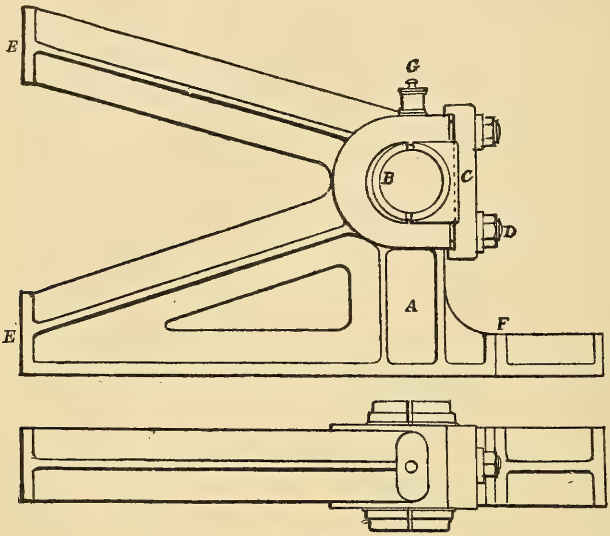


Fig. 300.—Main Framing of + Section.

A, Frame. B, Brasses. C, Cap. D D, Bolts and nuts. E E, Flanges for bolting to cylinder. F, Flange for bolting to condenser.

secured to the keelson or engine bearers by long bolts passing down to the under side of the bearers, with cross bars of cast iron at the under side; in this way the whole depth of the engine bearer is secured. All the bolt holes should have proper bosses cast on the framing, to suit the bottom and other flanges connected to the cylinder and condenser, so that a fair bed for the nuts can easily be faced up. The brasses for the pillow blocks are fitted just as in any other arrangement lying on its side, and are secured by caps of cast or wrought iron; each cap has two large bolts passing through it into holes cast and bored out in the casting, and fastened with cotters. The cap is fitted with clips at the top and bottom, nicely fitted to the pillow block, to prevent its sides springing; and the nuts for the bolts are fitted with washers and set pins, to prevent them becoming loose. All the work connected with the pillow

blocks must be well executed, for the main stress is directly taken on these bearings. When the distance between the cylinders is great, leaving a long centre part on the cranked shaft between the cranks, the centre bearing should be increased in length, so that no undue strain is taken on the cranked shaft; in fact, the shaft should be always supported as close to the cranks as is practicable. All the brass bearings are recessed for the reception of white metal, which is poured in while in a fluid state, a cast-iron core piece, somewhat less than the diameter of the shaft, being first inserted

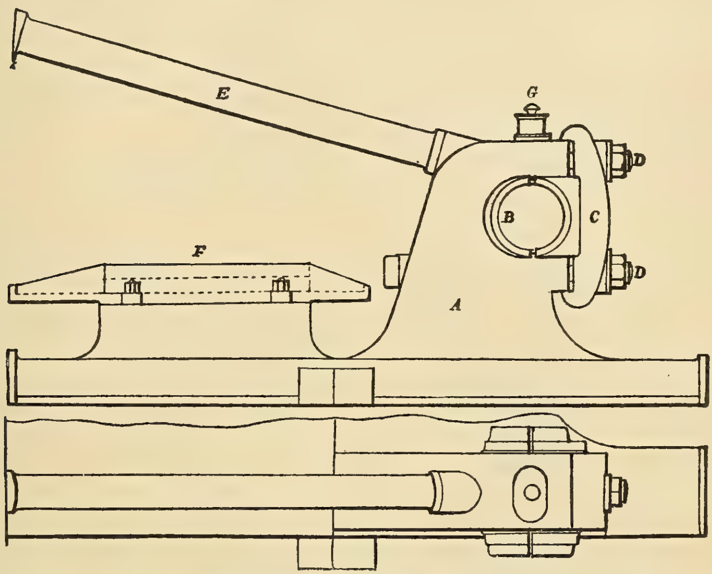


Fig. 301.—Main Framing of Box Section.

A, Frame. B, Brasses. C, Cap. D D, Bolts and nuts. E, Wrought-iron stay. F, Slipper guide. G, Oil cup.

in the bearing, so as to keep the white metal in its place; the half brasses are held together prior to this operation, and are bored out in the lathe and then separated. In this way fair work is secured; but some makers prefer boring out the brasses *in situ*, and no doubt when properly executed this plan has its advantages. In most machinery there are numerous fittings which can be conveniently cast on the main framing, or bolted on fitting strips left for that purpose; and proper attention to these points shows the skilfulness of the designer, and saves much work afterwards.

The box form of framing differs materially from the I and +

sections, although the brasses are also fitted in lying on their side, in order to adjust them in a direct line with the strain given off from the piston. The part of the bottom frame which forms the connection between the cylinder and the condenser is retained, but the top part is dispensed with, and a wrought-iron stay introduced, keyed through a boss bored out for its reception in the head or pillow block; on the other end of this stay a flange is formed for securing it by bolts and end keys to the cylinder at the side of the steam jacket. Between the bottom part of the framing and the cylinder a bed plate is introduced, on which raised parts are cast to receive what is termed the slipper guide plate for the crosshead of direct-acting single piston-rod arrangements. This part of the framing extends across the engine, embracing all the pillow blocks for carrying the cranked shaft, which blocks are also cast entire along with the bottom frame plate; but at the condenser end parts are cut out in the bottom having merely projections opposite the bearings for bolting to the condenser. This form of framing has a strong yet light appearance, and cannot be excelled for the peculiar type of engine for which it is designed, as all the parts are easily reached—a great desideratum in the marine engine; while the whole framework is firmly united to the keelsons by one broad base plate.

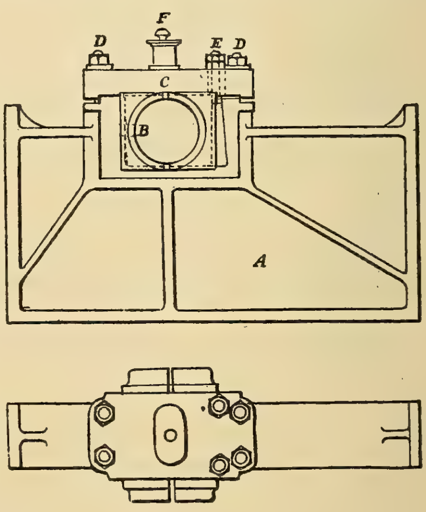


Fig. 302.—Main Framing with Adjusting Wedges.

A, Frame. B, Brasses. C, Cap. D D, Bolts and nuts. E E, Adjusting wedges. F, Oil cup.

In another form of framing, Fig. 302, we have the means of tightening up the main brasses by wedge pieces let into the pillow blocks. This frame extends from the cylinder to the condenser, with ribs and feathers cast along with, and in a direct line with the sides of the pillow block or bearing piece, the cap for holding down the brasses being placed on the top, instead of on the side as in the previous examples. Between the brasses at the cylinder end two wedge pieces of wrought iron are introduced, extending across

between the flanges, having a spindle forged on, and passing through the cap; they have a screw cut on the end with nut and lock nut fitted, by which means the brasses can be tightened up or adjusted at any time. In other arrangements a single wedge piece is introduced, having one central spindle fitted with two nuts for tightening up against the cap. Some makers introduce the brasses in four parts, one at each side and one at the top and bottom; by this means they can be adjusted vertically and longitudinally.

The condenser.—We now come to consider the arrangements for effecting the condensation of the steam with ordinary injection condensers. All condensing vessels should be constructed as simply as possible; and the arrangement of the water pipes leading into and from them, as well as valve seats, discharge chambers or hot wells, and all their various fittings, requires careful consideration. Where large flat surfaces are required, they should be well strengthened with ribbed bars in the casting; some makers use wrought-iron stays, which tend greatly to strengthen the condensing vessel against collapsing. The other parts of the general casting must be well bound with the various divisions required for the air pump and valve fittings. The capacity of the condenser is greatly affected by the size of the exhaust pipe from the cylinder; this pipe should have a large area, so as to freely pass the steam to that part of the condenser where the water from the sea is showered in; thus the large pipe receives the steam, which is at once condensed, and the capacity of the condensing vessel need not be so large as when the exhaust steam finds its way into a condenser placed alongside of a cylinder having no pipe connection.

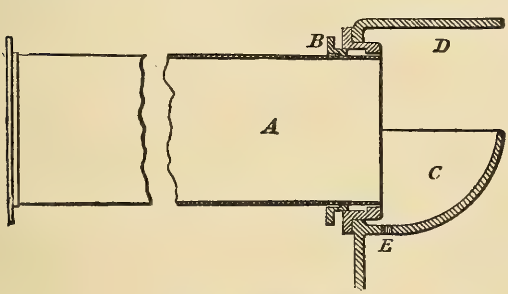


Fig. 303.—Exhaust Pipe.

A, Pipe. B, Stuffing box and gland. C, Baffle plate. D, Condenser. E, Hole for running off condensed steam.

The exhaust pipe should be fitted with an expansion joint, which is generally placed on the condenser casting, the end of the pipe passing through a loose hoop placed at the bottom of the stuffing box; by this means the pipe can be angled into its place without disturbing the cylinder or condenser. The loose hoop and gland

being placed on the pipe in the first instance, the hoop is then slipped into its place, and the gland pressed down on the hemp packing in the usual manner; the other end of the pipe is secured by a flange bolted to the cylinder. There are also other forms of expansion joints. Some have hollow discs formed on the body of the pipe, with end flanges for securing the pipe to the cylinder and condenser, thus forming a rigid stay between the two, but having the power of expanding by compressing the flat discs, and contracting when the strain is off by opening the disc plates. We prefer, however, the usual mode with stuffing box and gland. The position of the condensing chambers varies, and depends greatly on the location of the air pumps. When these are placed together, one on each side of the middle frame for carrying the cranked shaft, the condensers are then generally in a line with the outer frames, or fore and aft of the outer lines of the cylinders. In return connecting-rod engines, with the discharge chambers placed between the centre lines of the cylinders, and in similar arrangements of air pumps, the condensing chamber and discharge chambers are both placed between the centre lines of cylinders; this plan necessitates the cylinders to be placed further apart from centre to centre—that is to say, when the air pumps are located at the side of the motion or guide bars for the crosshead. Sometimes the air pumps are arranged underneath the motion bars, having the discharge chamber at the middle between them, and the condensing chambers on each side; while, in other examples, with one air pump on the outside of each outer frame, fore and aft, the condensing chamber and discharge chamber are cast together immediately over the air pump. In direct-acting single piston-rod and double-trunk engines, the air pumps are always placed one on each side of the centre frame, having the condensing and discharge chambers located immediately above them; while in plunger air pumps with single-acting arrangements for foot and head valves, suited for single trunk and return connecting-rod engines, the condensing and discharge chambers are placed immediately over the pumps.

The general arrangement of all these forms of condensers, exhaust, discharge, and injection pipes, air pumps, with foot and head valves, &c., cast in one or more castings, is as follows. When the air pumps are arranged one on each side of the middle frame, there are generally two separate castings, all the fittings for which are kept quite independent. The air pump in all the examples

under notice, whether fitted with an internal plunger or a simple piston, is of the double-acting type, and is worked directly off the steam piston by means of a rod connected to it, having packing glands on cylinder end and air-pump cover. When the pumps are placed as above described, the foot valves are underneath and the head valves above them; there are separate chambers for the foot valves at each end, but the head valves are fitted in one chamber common to both ends. Doors for the foot valves are fitted at each end, one of which forms the cover, and the other is an ordinary door; on each of these doors a circular pipe piece is cast, for filling up the space above the foot valves, so as not to leave so much dead water in the foot-valve chambers. The doors on the discharge chamber containing the head valves are of the ordinary description; these as well as the other doors are generally bolted by stud bolts and nuts. Two deep feathers are cast along with the hot well, which forms an air chamber tending to relieve the shock caused by the rapid discharge of the water. The discharge pipe is fitted to one end of the hot well, at the top, and is placed in communication with one pipe overboard common to both air pumps. The condensing chamber is on the opposite side of the centre line of the cylinder in regard to the air pump, the exhaust comes in at the top, and the injection pipe immediately under it. The condensing chamber is ribbed and cast with circular parts, which are bored out for the reception of the air-pump barrels; these are cast in brass, and fitted with solid-ended pistons of the same material.

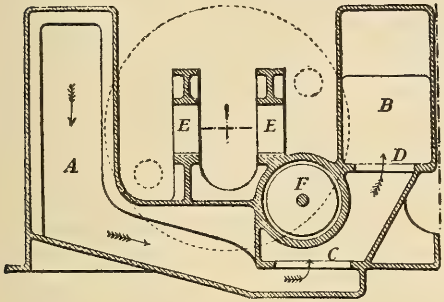


Fig. 304.—Air Pump with Condenser outside and Discharge Chambers at centre.

A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E E, Guide bars. F, Air pump.

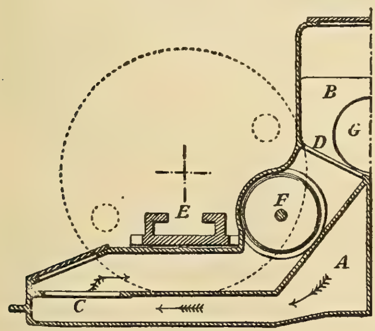


Fig. 305.—Air Pumps with Condenser and Discharge Chamber at centre.

A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E, Guide for piston-rod crosshead. F, Air pump. G, Discharge pipe.

The snifting valve for all condensers is fitted as low down as possible.

For similar arrangements of air pumps situated on each side of the middle frame, the foot valves are placed low down on the other side of the centre line of the cylinder in regard to the air pump, with the head valves in one chamber common to both, arranged between the air pumps; the doors for getting at the valves are placed on the top of the valve chambers, which is found a very convenient and handy arrangement. One discharge pipe, placed centrally with the hot well, serves for both of the pumps. The exhaust steam comes in at the top end of the chamber, and the water falls down underneath the air pumps, the condenser being partly above and partly below the pumps, and having a division cast in for separating and strengthening it. The injection valve can be placed above the exhaust pipes, and thus shower the injection water down on the steam, instead of meeting it as in the previous example.

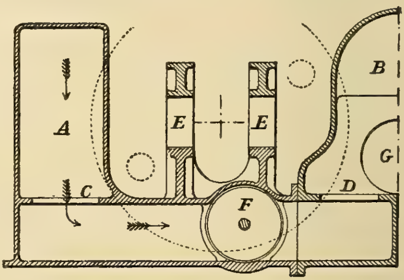


Fig. 306.—Air Pump with Condenser outside fitted with inverted Foot Valves and Discharge Chamber at centre.

A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E E, Guide bars for piston-rod crosshead. F, Air pump. G, Discharge pipe.

When the air pumps are situated underneath the motion bars, a good plan is to invert the foot valves, placing them in the bottom of the condensers, which are seated in a line with the outside frame; thus the condensing water and the condensed water from the steam fall into each suction chamber by their own gravity. In this arrangement the head valves are placed in a central chamber between the pumps; and this chamber has one discharge pipe common to both sets of air pumps. The exhaust steam enters at the top, the injection pipe is placed under and showers the water upwards to meet the steam, care being taken that the water cannot pass into the exhaust pipe. The injection pipe, when placed below the exhaust pipe, should always be pierced with holes, to shower the condensing water meeting the steam, instead of pouring it down vertically; by this means the water and steam are brought into better contact, and form a more rapid vacuum.

When the air pumps and condensers are arranged in a line with

the outside frames, the foot valves are inverted, the head valves being over the pump, with a discharge chamber and pipe, having the condenser immediately over it, separated by means of division plates in the casting; the exhaust pipe is placed at one side, and the injection pipe on the opposite side arranged for showering the water downwards. A bed plate for carrying the guides for the crossheads, &c., lies between the two pumps, and forms a very convenient starting platform, nearly on a level with the engine floor plate. Some engineers, however, make use of this space for arranging the condensing chambers between the guide bars, with the air pumps placed as before inside of the outer frames. The foot valves are placed at the bottom and side of the air pump, and the head valves immediately over them, with side doors to each, and a discharge pipe for the pump. The exhaust pipes enter at the top of the central condensing chambers, and the injection pipes are placed lower down. It is advisable with this form of condenser, at least for engines of great power, that the pumps should be separate castings; provision should also be made on the patterns for attaching and fitting to the general casting the feed and bilge-water pumps, which are generally worked off arms keyed on the piston rods, or with studs fitted to the crossheads, or even with direct rods from the steam piston. We have here given examples of condensers with their adjuncts which are in general use; but it will be understood that a variety of forms can be arranged for return connecting-rod engines.

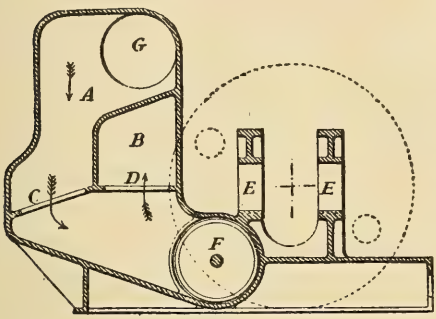


Fig 307.—Air Pump with Condenser outside fitted with inverted Foot Valves and Discharge Chamber outside, all in one casting.

A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E E, Guide bars for piston-rod crosshead. F, Air pump. G, Exhaust pipe.

We now turn to arrangements that have been adopted for direct-acting, single piston-rod, and double trunk engines. There is a great similarity in the various parts of these, chiefly owing to the air pumps being located one on each side of the middle frame for carrying the cranked shaft. The condenser is situated centrally above the pumps, having the foot valves inverted, so that the water

falls into the pump chamber by gravitation; the head valves are placed at the side and above the line of foot valves, with a hot well for each pump fitted with separate discharge pipes overboard. With this arrangement of foot and head valves air is not so liable to collect between the piston and valves; it is therefore preferable to have an air valve—should it be desirable to place the discharge valves below the line of head valves—arranged at the highest point in the foot-valve chamber, by which the air is forced into the discharge pipe overboard. The exhaust pipe is of a large diameter, suited for both engines, placed in the centre of the condenser, and the injection pipe is placed at the top on the same centre line, thus the water is showered down on each side of the condensing chamber: this arrangement is very effective. In other arrangements the valves are placed *vice versâ*, the condensing chambers being at the side, and the discharge chamber placed centrally above the pumps, with one discharge pipe overboard; while there are two exhaust pipes, each passing into a separate condenser, with the injection pipes underneath. This arrangement has the advantage of the condensers for the cylinders being separate from each other, and this enables us to regulate the injection water required by each, which we cannot do when one injection pipe serves for both condensers. These condensers, when required for engines of ordinary power, are generally cast in one piece, but for heavy engines they should be two separate castings, with air pump and adjuncts arranged as in the previous examples.

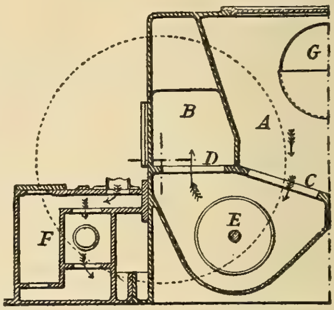


Fig. 308.—Air Pumps with Condenser at centre fitted with inverted Foot Valves and Discharge Chambers at side, all in one casting.
A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E, Air pump. F, Feed pump. G, Exhaust pipe.

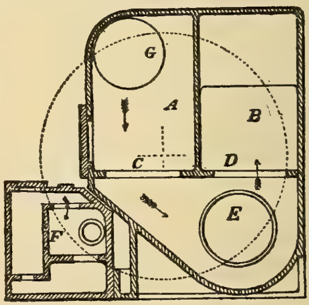


Fig. 309.—Air Pump with Condenser at side fitted with inverted Foot Valves and Discharge Chamber at centre.
A, Condenser. B, Hot well. C, Foot-valve seat. D, Head-valve seat. E, Air pump. F, Feed pump. G, Exhaust pipe.

THE SURFACE SYSTEM OF CONDENSATION.—Before describing the construction of the condenser for the surface system of con-

densation, we shall notice the disadvantages attending the injection system for the condensing of steam in marine engines. The chief objection doubtless arises from the necessity for using a continuous supply of salt water in the boilers, the salt accumulating to such an extent that a high degree of heat is required to raise the steam. This accumulation of salt proceeds so rapidly, that it is necessary to blow off the water in the boiler every two hours or so, the feed from the hot well at the same time is turned on, thus the hot brine being blown off, and replaced with a colder fluid, the temperature of the water in the boiler is greatly reduced, and requires much valuable fuel to keep it up to the proper working point. The rapid incrustation that takes place is likewise a serious objection, as the scale formed all round the parts immediately exposed to the action of the flame is a very bad conductor of heat, and not only impedes the free transmission of the heat to the water, but in many parts of the boiler it forms to such an extent that rupture of the plates takes place, more especially on the back parts of the furnaces where the flame returns through the tubes—necessitating frequent inspection, for the purpose of cleaning the boilers, and removing the incrustations, so as to prevent the plates wearing out too rapidly. In fact, for the high-pressure compound engine system, the injection condenser has been discarded, because distilled water is preferable to impure salt water; and with proper precautions we can safely adopt high-pressure steam with fresh water, and thereby save much valuable fuel.

The action of surface condensation may be familiarly illustrated by the well known deposition of moisture on the windows of a crowded room, due to the cooling surface of the glass. So with the steam from the cylinder: surface must be provided, and cold must be applied to that surface, so that with cold on the one side, and the steam impinging against the cold surface on the other, the caloric is extracted, and water flows down, similar to that on the window. Thus when the boilers are provided in the first instance with pure water, it is used over and over again, with just sufficient water injected from the sea to meet the waste, and keep the density of the water in the boiler at about the same as the water in the ocean, this being considered in practice very safe. And as water requires a large surface in the boiler for the heat to act upon it in raising steam, so in condensing the steam rapidly we must have a large amount of cold surface for it likewise. The surface condenser

is simply an arrangement of tubing placed in a convenient vessel surrounded with water; in some cases the tubes are filled with water, in others the water in the vessel flows all round their external surface. This water must be kept constantly flowing through the vessel, so as to maintain the refrigerating surface at a proper working temperature. For this purpose a circulating pump is fitted, which draws the water through the tubes or around them, as the case may be; in other arrangements the water is forced through or amongst the tubes. The water from the condenser is carried off by an air pump similar in construction to that used for ordinary injection condensers, and is delivered into a separate vessel, from which it is pumped into the boilers, in some instances directly by the air pump, but usually feed pumps are fitted for the purpose. In some convenient part of the condenser a valve and inside pipe are fitted, perforated with slits or holes for showering into the condenser the sea water necessary to keep up the requisite amount of feed for the boiler.

We now come to consider the manufacture and arrangement of surface condensers. The tubes vary from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch internal diameter, thickness about $\frac{1}{16}$ inch; generally $\frac{3}{4}$ inch outside diameter; they are made of composition metal, and are known by the name of cold-drawn composition tubes. The tubes for government contracts are tinned outside and inside to prevent chemical action. They are 9 feet long.

The tube plates are of copper, and vary in thickness from $\frac{9}{16}$ inch to $\frac{13}{16}$ inch; they are fitted to plane surfaces on the casting forming the vessel containing the tubes, and are secured with composition metal bolts and nuts. A variety of plans are adopted for making the ends of the tubes air and water tight. The original plan (Fig. 310), still much used, consists in forming screwed stuffing boxes in the tube plate, the packing being a tape of cotton or linen sewn together, which is slipped over the ends of the tubes, and pressed into the stuffing box with a screwed gland. These glands are manufactured from solid rolled tubes of composition or Muntz metal, and can be obtained of suitable lengths; the inside diameter must slip easily over the tubes in the condenser, while the thickness is regulated by the size of the gland, so that a proper thread is cut in a similar way to bolts in the common screwing machine; they are cut off into proper lengths by a circular saw, and notched in a machine with two notches, for screwing them into the stuffing box

with a screw driver. Another mode of making the tube joints is with a sheet of india rubber having holes suited to the pitch of the tube. The holes are left smaller than the outside diameter, and when the tubes are all in position, being merely passed through plain holes drilled in the tube plates, the india-rubber sheet is laid over them, and an outside plate is bolted up against it, which plate is recessed for the reception of the tubes, and leaves a narrow edge round each tube; thus with the pressure, and the holes in the india rubber being much smaller than the diameter of the tube, a raised flange of india rubber is formed around each tube, and the tubes are gripped by an elastic medium, while the pressure transmitted through the plate by the bolts to the flat surface of the india rubber keeps it in perfect contact with the plate, and a good joint is obtained. Some engineers, however, think that each tube should be made air and water tight separately, so that if a joint gets out of order it can be repaired without disturbing the whole series; besides with such thin tubes it is an object to have the joint elastic, so that the tubes can expand and contract easily. With these objects in view the author has arranged a packing ring of a peculiar construction. The holes in the tube plate are bored parallel, and then tapped; a gland or screwed nut having a recess for a ring of india rubber or any other elastic medium is fitted to each hole. The india rubber ring is a good fit in the recess, and is put in place by merely squeezing it together; its inside diameter is made smaller than that of the tube, according to the amount of grip required; and to facilitate the operation of tubing, a loose cone plug is inserted in

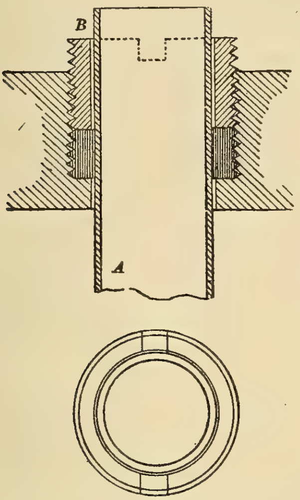


Fig. 310.—Tape Packing for Tubes.
A, Tube. B, Packing gland.

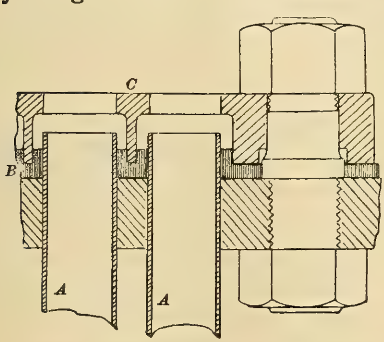


Fig. 311.—Sheet mode of making the Tubes tight.
A A, Tubes. B, India-rubber sheet. C, Plate.

the ring, and the nut being placed over the tube when in position, it is screwed up, then the cone is forced through the india rubber and expands it for the reception of the tube; in this way the ring is spread out, tightly filling the recess, and binding the tube firmly; the nut is screwed hard up on the tube plate, against a washer, or simply metal to metal, having a little red lead interposed. By this plan the tubes can be readily and quickly made tight, and the elasticity of the ring allows of free movement for expansion and contraction. When india rubber is used the tube ends should be tinned to prevent the deterioration which takes place when brass and india rubber are in contact. In some arrangements when the water is forced through the tubes, their ends are made tight with a simple flat ring washer of india rubber, placed over the tube tightly, the flat end surface bearing on the tube plate, which is recessed for its reception, and in others wooden plugs are used, driven over the tubes, and firmly held in the tube plate, the expansion of the wood when wetted making a very good joint.

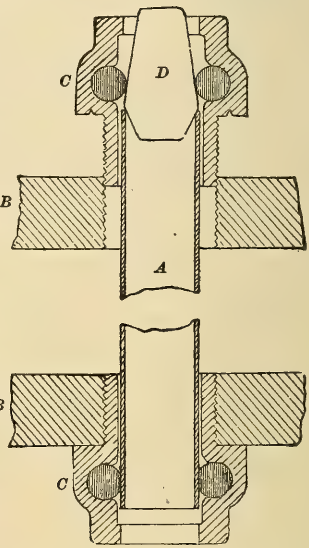


Fig. 312.—Packing Ring for Tubes.
A, Tube. B B, Tube plates. C, Screwed gland and india-rubber ring. D, Cone.

The arrangement of the refrigerating surface now falls to be noticed. When the water passes through the tubes and the steam all around them, we obtain a larger amount of surface than when the steam is condensed inside of the tubes; but in the former case any incrustation that takes place tends to choke up the spaces between the tubes, and so far renders them useless, as there is no possibility of getting them cleaned; whereas, when the steam is condensed inside of the tube, the surface can be cleansed occasionally. Again, should any of the tubes require repacking at sea, with the water circulating around them, the large covers which form part of the condenser require to be taken off, and should any leakage occur through the joint being imperfectly re-made, air finds its way into the chamber and impairs the vacuum; whereas, when the water passes through the tubes, with any leakage occurring, the

water simply finds its way into the ship, and the working of the engines is not sensibly affected. Looking, however, at all sides of the question, we may conclude that the advantages are in favour of inside condensation,—provided that the circulation of the water is properly attended to and uniformly distributed all round the exterior surfaces. When the surface system of condensation was first introduced into side lever engines for the Royal Navy, 2800 square inches of tube surface was adopted for the condensation of 60,000 cubic inches of steam per minute, the quantity of cold water injected being 10 gallons. To compare these quantities with present practice, let us take an example of an engine of 400 nominal horse-power, having 3170 square inches of area in each cylinder, with a piston speed of 300 feet or 3600 inches per minute:

$$\frac{3170 \times 2 \times 3600}{60000} = \frac{380 \times 2800}{144} = 7389.$$

We thus have 7389 square feet of tube surface, equal to 18·4 square feet per nominal horse-power. It will be observed that this result is about the same as that given for total heating surface of boiler per nominal horse-power, although it is in excess of present practice, 15 to 16 square feet of condensing tubes being now considered sufficient. To find the quantity of water required for condensation: a cylindrical foot of water equals 5 gallons, 10 gallons will be contained in 3456 circular inches, and as 380 times 60,000 cubic inches of steam passes the engine per minute, we have

$$\frac{3456 \times 380}{3600} = 364 \div 2 = 182$$

circular inches of area for each pump, when two pumps of the double-action type are fitted—or a diameter of say 14 inches will be enough for each of the two circulating pumps. (See pages 508–510.)

The air pumps are generally made of the same capacity as for plain injection condensers, and when one circulating pump is fitted, it is of the same capacity as the air pump; one set of patterns thus serves for both, and in the event of using the condenser with plain injection, valves are so arranged that the circulating pump can be used for an air pump. The circulating pump should be fitted with a valve for turning on the bilge water, in case of great leakage in the ship; a valve must also be placed on the pipe for shutting off the sea-water. Should both of the pumps be used as air pumps (in cases of failure), a bilge injection valve should be fitted. When

a separate centrifugal pump is used, driven by a small engine, for circulating the water, and two air pumps are fitted, the centrifugal pump should be arranged to pump the bilge water overboard, and one of the air pumps turned into a circulating pump, the requisite valves being placed so as to be opened at the shortest notice. To provide against any accident to the surface system, a plain injection valve is placed on the condenser, and a valve is also fitted at some convenient part to drain all the water out of the condenser when necessary.

Various arrangements of the tubes for surface condensers are adopted. For direct-acting horizontal engines of the return connecting-rod type, they are arranged vertically, placed between the crosshead guides in one, or else there is a separate condenser for each cylinder. The steam from the cylinders enters above the top plate, and being condensed falls directly through the tubes into the air pump, which is situated on the inside of the outer frame, and worked directly from the steam piston, while the circulating pump occupies the same position as regards the other cylinder; the water is drawn through the vessel containing the tubes, coming in at the top, circulating around the tubes, and being drawn away, instead of forced, by the circulating pump. The bottom part of the condenser is generally cast in two, containing the guide bars for the piston-rod crosshead, the chamber for the gun-metal air pump or circulating pump, barrel, valve seats, air vessels, &c. The flange for holding the bottom tube plate extends the length and breadth of the casting between the guide bars, and is planed all over; the bottom tube plate is fitted on it, the vessel containing the tubes is placed over it, and the top tube plate secured on the top. Above this is placed the top part of the condenser, where the steam enters; it is fitted with covers on the top for getting at the tubes, the bottom joints are reached through a door on the bottom chamber of sufficient height for a man to enter. Some arrangements of the

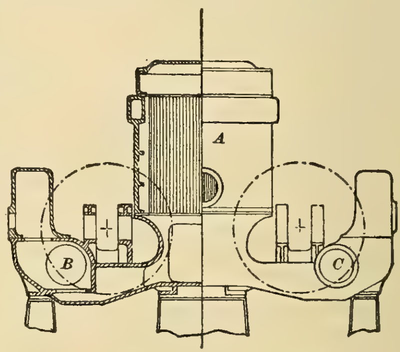


Fig. 313.—Vertical Arrangement of Tubes for Return Connecting-rod Engines.

A, Tube chamber. B, Air pump. C, Circulating pump.

vertical type have a circulating pump worked directly off the piston, with an arm keyed on the bottom piston rod for taking the air-pump rod; two circulating and two air pumps are fitted, in other words the separate condensers have each a circulating and air pump. As the water, either from the sea or from the condensation of the steam, gravitates directly into the pumps, this arrangement is very effective, although the circulation of the water is not so good as could be desired—a fault inherent in all cases where the condensation takes place inside of the tubes; nevertheless, when the water passages are properly arranged, inside condensation is to be preferred, as there is then some possibility of cleaning the tubes from lubricating matter carried over by the steam. As an improvement on the vertical arrangement, some engineers have made the condenser cylindrical, with a space in the centre for the steam pipe from the cylinder, around which the tubes are arranged in rings. The exhaust steam pipe is perforated with holes for distributing the steam equally; the condensing surface is on the outside of the tubes, the water circulating through them. In some cases the condenser is fitted with circulating and air pumps worked directly off the piston, in others the air pumps work direct, with a centrifugal circulating pump driven by an auxiliary engine.

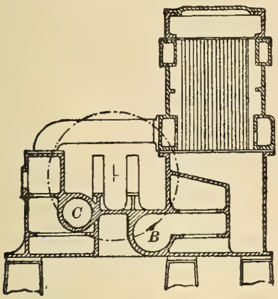


Fig. 314.—Vertical Arrangement suited for each Cylinder independently.

A, Tube chamber. B, Air pump. C, Circulating pump.

The horizontal arrangement of tubes next claims attention. For direct-acting horizontal engines the tubes are placed fore and aft the ship, arranged in three divisional parcels, with the view of giving time for the transit of the circulating water which is being forced; and this passes in the first instance through the bottom row, returning through the middle row, and then passing through the third or top row before escaping overboard,—in this way securing a more equal distribution. The condenser vessel may be cast in one or more pieces, with all the necessary passages, valve seats, &c., for the pumps; the joint faces for the tube plates are all planed, and the tube plate accurately fitted. As the doors for getting at the tubes are placed at the ends of the condenser, both of the tube plates are easily managed, whether as regards fitting in the tubes in the workshop, or repairing leaky joints at sea. To ease the passage of

the water through the tubes, flat air vessels are cast along with the end doors, by which the flow of water is rendered smoother and more equal. The steam enters at the top through an exhaust pipe at each corner, the water from condensation falls down amongst the tubes and is carried away by the air pumps; one pump only is fitted to engines of small power, but heavier engines have two air and two circulating pumps.

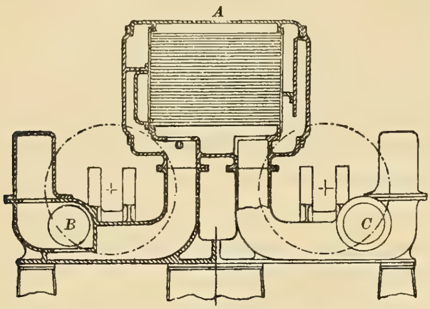


Fig. 315.—Horizontal Arrangement of Tubes for Return Connecting-rod Engines. A, Tube chamber. B, Air pump. C, Circulating pump.

From the great number of such tubes required to give the necessary cooling surface, or about 2 square feet per indicated horse-power, the length reaches in large vessels to many miles of tubing; thus in the surface condensers for the new Inman steamer *City of Rome*, the total length of tubes is about 17 miles.

It appears to be of little consequence whether the water flows inside or outside of the tubes, so long as a good circulation is kept up.

Sometimes the tubes are arranged independently for each cylinder, the water from the circulating pump only passing through the tubes twice, instead of three times. The pumps are located on each side of the middle frame, and are worked directly off the piston of each cylinder. They are of large diameter, one end being fitted for the circulating pump, and the other end for the air pump; thus for each function this arrangement may be termed a single-action double-acting pump. There is one central chamber and pipe for the suction to the circulating pumps, which first discharges the water right and left into a chamber common to both, and then through the tubes; the water returns through the top row, and is discharged into one central chamber, with one pipe overboard for both pumps. The arrangement of the valve seats is simple: they are sometimes placed at the side of the pump, sometimes at the top and bottom. It may be questioned whether single-acting circulating pumps are preferable to smaller sized double-action pumps. Many engineers are in favour of the double-action type, but consider, so long as a sufficient quantity of condensing water passes through or amongst the tubes, that a single-acting pump, discharging into a capacious air vessel, makes the flow quite uniform enough for all

practical purposes. The doors in the arrangement of condenser under notice only admit of inspecting one end of the tubes; for packing their central ends a manhole is arranged in the bottom and top chambers, through which the water enters the tubes at the bottom, and from which it is discharged overboard at the top. A plate abutting on both tube plates forms the division between the two. This arrangement is very good for engines of large power, as the tubes are of a suitable length, neither too long nor too short.

To facilitate the water from the condensed steam flowing away from the tubes, when condensation takes place on their internal circumference, the tubes have been arranged lying at an angle. They may be so disposed right and left, or all in a cluster; when arranged right and left, the central chamber, as in the foregoing example, becomes the exhaust steam chamber, instead of the water chambers. The air pumps are arranged on each side of the outer frames of the engine, and the circulating pumps on each side of the central frame; the suction valves for both pumps are inverted and placed above the pumps, while the discharge valves are arranged alongside, the circulating water flowing amongst the tubes at the bottom end near the central frame, and ejected from the vessel containing the tubes at the opposite corner at the top: thus the water is well distributed amongst the tubes—a very necessary thing to attend to in all arrangements.

The valves for the pumps are of the round disc type, made of india rubber, having grated seatings and guards of brass. Some of these valves fold up all round against a saucer-shaped guard perforated with holes, and are secured to each hole in the condenser by a cross bar of iron and a single bolt. This bolt passes through the centre of the bar, seating, and guard, and is secured with one nut at the top, pressing the guard and seating downwards, and drawing the cross bar upwards against the under side of the metal surrounding the hole in the condenser casting; but the general way is to secure the guard and valve by a screwed stud with a nut at the top to a large plate containing all the gratings for valves, the plate being secured over one large hole in the condenser casting by gun-metal stud bolts and nuts. Sometimes the guards are made quite flat, the valve moving upwards and downwards on the boss of the guard, the central hole in the india-rubber disc being made slightly larger, so that it moves easily; this arrangement can be secured with a cross bar, or with stud bolts, on a plate common to

all the valves, as before described. The gratings for these valves are formed of ribs radiating from the centre, having one or more concentric rings, keeping the area of each hole in the grating equal to about 1 square inch. The ribs on the guard radiate from the central boss, and the ends of the elongated apertures are rounded or left square as taste may dictate. Other forms of valves are oblong shaped, folding up against a flat guard, the india rubber being secured at the middle with stud bolts; the holes in the gratings being made hexagonal, formed around a circle 1 inch in diameter. This grating resembles a honeycomb, and may be said to combine the greatest area with the least material, thus obtaining more free way for the passage of the water—a very desirable point to attain in designing pump valves. For this object a valve seat has been designed by the author in which five discs can be placed in about the same space as is usually occupied by one; the seating is in the form of a square box open at the bottom, with a flange all round for securing it to the condenser, one valve being placed on the top and one on each of the four sides. This plan can be modified by making the valve seating cylindrical, the side valve being simply a band of india rubber, secured at one end to the cylindrical seating, and a round disc valve placed on the top. The action of the band valve is one of expansion and contraction as it opens and shuts with the reciprocating motion of the pump piston, or plunger if so fitted. It is scarcely necessary to state that india-rubber valves will work in any position, whether lying flat, or at an angle, or even inverted; the latter position is fast finding favour, where the passages of the pump are so arranged that the water gravitates into the pump chamber instead of being sucked or drawn in.

The pistons for the circulating pumps of direct-acting horizontal engines are packed with a metallic ring; in some instances wood packing has been adopted, lignum-vitæ being preferred. In other cases plungers instead of pistons are used. The plunger consists of a cylinder of brass working in a central stuffing box, hemp packing being used in the form of a gasket. The cylinder forms as it were the pump barrel and piston, as in the double-action pump: it is worked directly off the steam piston, with a small rod secured to the cylinder with a single nut. It may be argued that the plunger is heavier than a plain piston, but it must be remembered that as it is surrounded with water, it partially floats as it were

in the fluid, consequently the wear is much reduced; however, for surface condensers it is not so compact as a plain piston. Sometimes the water chambers at the ends of the pumps are partially filled up with a cylindrical casting, formed on the end covers; the piston rod works through this at one end, and it is left plain at the other end of the pump,—that is to say, no stuffing box is required, but the cylindrical filling-up piece is simply cast along with the end cover.

Air Pump.—The air-pump barrel is cast in brass, with fitting rings at each end and at the middle, which are turned to fit the parts bored out in the condenser casting; the barrel is secured by lugs cast on the end, with brass bolts for firmly bolting it to the condenser. When internal plungers are used, the barrel of the pump forms as it were the central gland, which is packed with hemp in the usual manner. All the bolts and nuts used in the internal fittings should be of brass or Muntz metal; this is absolutely necessary, for with wrought-iron nuts oxidation rapidly takes place, and the violent motion of the water passing through the pumps would wash away the rust as it formed, and soon render the bolts useless.

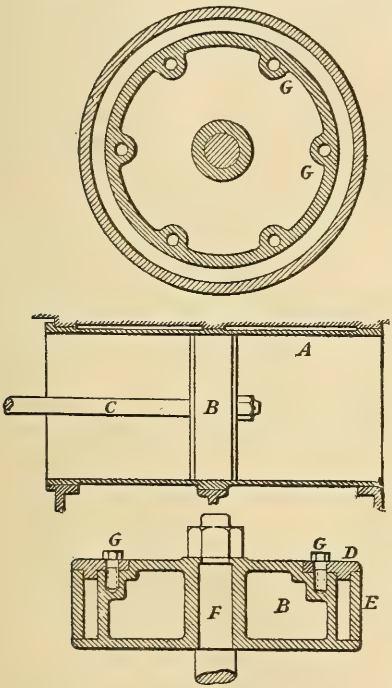


Fig. 316.—Air-pump Barrel and Piston.

A, Barrel. B, Piston. C, Rod. D, Junk ring. E, Packing ring. F, Parallel part on rod. G G, Tap bolts.

The pistons are of the usual kind, cast in brass; some are merely recessed for the reception of a plaited gasket, while others have metallic spring rings, the piston being fitted with a junk ring held down with bolts; a gasket is sometimes placed in the space between the brass packing ring and the body of the piston, thus dispensing with springs for keeping the packing ring up to the face of the barrel. Hydraulic pressure is conveniently employed in some pumps

for this purpose. A small hole is bored at each end, in communication with the open space between the ring and the piston, and the mere forcing of the water causes a pressure inside, which presses the packing ring outwards against the barrel of the pump. When one ring is used, a small india-rubber ball valve opening inwards, placed at both ends, will tend to make the action more perfect; as the piston is going forward the front valve would open and the back one would shut, and *vice versâ;* thus there would be no escape through the piston, but probably this is not required, as a very small hole suffices, and the escape is but little felt; and if two rings were fitted in recesses, one hole suffices at each end. Thin spring rings of brass have been used with advantage; in this case the piston is made quite solid at the ends, with three recesses turned out on the rubbing surface for the reception of the rings, which are truly turned a *very little* larger than the interior diameter of the pump; they are then sawn through at one part, expanded over the piston, and sprung into the recesses; in this way there is a slight spring in the rings, which keeps them well up to the surface of the barrel. Wood packing with lignum-vitæ has been often successfully used; the piston is cast as before, and the space for the packing is filled up entirely with curved blocks, which are made to overlap one another at the joinings, and then the ring is turned to the exact diameter of the barrel, the body of the piston being a trifle less in diameter. This arrangement is what may be termed a solid piston, and is one which can only be adopted with a material that expands in water; lignum-vitæ is well fitted for the purpose. Solid brass pistons without any packing have been tried, but did not succeed, as they soon failed to afford a perfect vacuum. Hollow plunger pistons have, however, been arranged, both internally and externally. In the former plan the plunger has a central packing

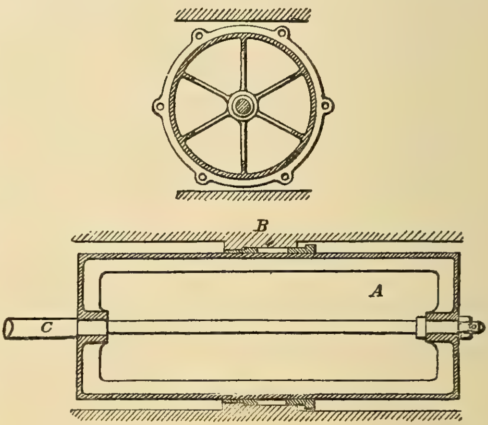


Fig. 317.—Air-pump Plunger and Gland.
A, Plunger. B, Stuffing box and gland. C, Rod.

gland for forming the joint between the two ends of the pump; it is solid at the ends, and has a boss at the centre, bored out for the reception of the Muntz metal rod, which is secured by a screwed part at the end with a brass nut, drawing up the plunger against a collar formed on the rod. In the latter plan the plunger is moved by a connecting rod working directly from the cranked shaft, having a bearing inside of the plunger. For this arrangement the bushes and glands should be made very deep; while in others, when the main connecting rod for the engine works a plunger, which in its turn moves the steam piston by rods attached to it, it is advisable to form the bottom bush of the gland the entire length of the stroke, thus supporting and taking the thrust of the connecting rod on a large surface. In this arrangement of air pump it is necessary to reduce the area of the plunger, by having a hollow guiding trunk at the other end, working through a suitable packing space and gland.

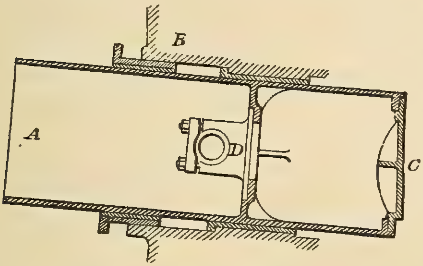


Fig. 318.—Air-pump Plunger and Gland.
A, Plunger. B, Stuffing box and gland. C, End cover. D, Bearing.

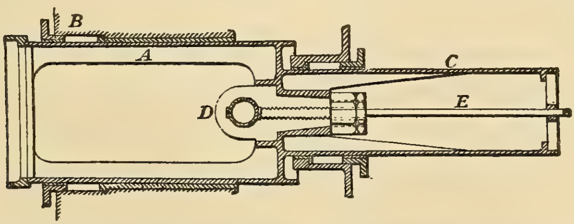


Fig. 319.—Air-pump Plunger acting as a guide for the Crosshead and Piston Rods.
A, Plunger. B, Stuffing box and gland. C, Hollow guide. D, Bearing. E, Rod for adjusting brasses.

All air-pump rods should be made of Muntz metal, secured to the rod from the main piston by a cotter passing through a boss formed on the wrought-iron rod which is bored out for its reception.

The *foot and head valves* are formed of discs of india rubber, working on brass seatings. They are introduced in all fast-going engines, to lessen the disagreeable sound caused by the metallic valves, and they have materially assisted in bringing the direct-action engine to that high state of perfection which it has now

attained. Still further to diminish the noise, the lift of the india-rubber discs is limited by means of a curved guard, having a boss at the centre; this boss rests on the seating, and is bored out for receiving one end of the holding-down bolt, the other end passing through a cross piece of wrought iron, which bears on the under side of the round hole over which the grating for the disc of india rubber is placed. The hole in the india-rubber disc should fit loosely round the boss formed on the guard, and in no case should the india rubber be pressed down on the seating. These gratings consist of annular rings and ribs radiating to the centre of the boss, thus forming a number of oblong holes through which the water passes. The guard also requires to be pierced with holes, as the discs of india rubber have a tendency to work or close slowly, were not the water acting on the top surface and pressing it downwards on the return stroke. Some of these valve seatings are secured by brass stud bolts and nuts, with lugs cast on the seating for bolting them down over the holes left in the condenser casting, the joint being made with a ring of india rubber recessed into the seating;

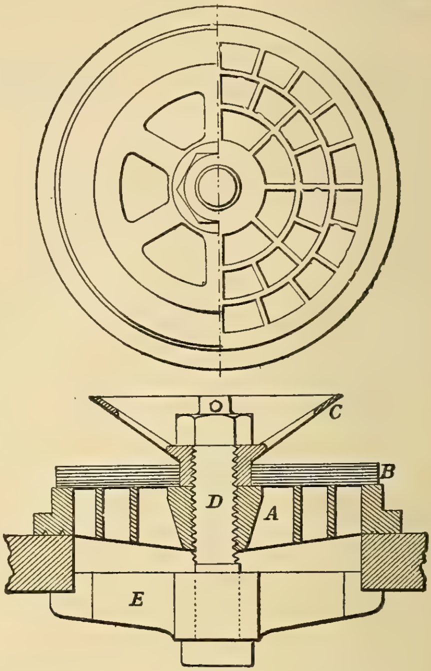


Fig. 320.—Single Valve for Air Pump.
A, Valve seat. B, India-rubber valve. C, Guard. D, Holding-down bolt. E, Cross bar.

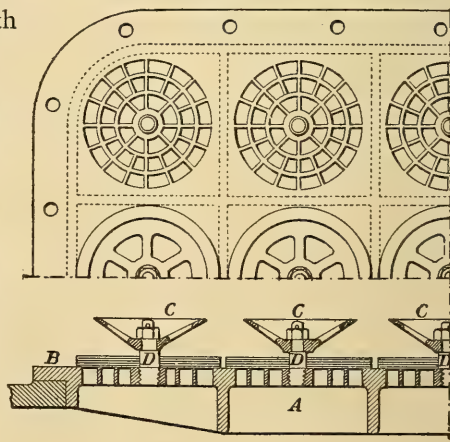


Fig. 321.—Arrangement of Valves adopted for Air Pump.
A, Grating. B, India-rubber valve. C C, Guards. D D, Studs for guards.

while the guard is secured to the seating by a plain bolt and nut. The plan now universally adopted is to cast a number of these circular gratings in one large brass seating, which is bolted down over the oblong holes left in the casting; this brass plate is strengthened with bars on the under side, and has a flange all round for the holding-down bolts, which are screwed in the casting as studs with nuts on the top; the guards are fastened down to the valve gratings by a stud bolt passing through each guard, having a nut bearing on the top of the guard; in other cases the stud is formed with a collar to screw up against in the grating, which collar is somewhat deeper than the thickness of the india rubber, and the guard is bolted down on the top of it. All the nuts on these studs should have split pins passing through the points of the bolts, to prevent the guards shaking loose. In some arrangements the valve seats are all bolted down to one brass seating, having a number of large holes left in it and bored out for their reception; and when the large plate is properly planed on the surface, and all the small gratings turned, the joints may be simply metallic, with a little thin red lead placed between the surfaces before they are bolted down. In some instances it is advisable to place a number of valves in a small space; with this object in view, as well as to decrease the circumferential opening of the valves, and yet give a large area for the passage of the water, the valve seating may be made in the form of a square box, open at the bottom, with side flanges all round for bolting it to the condenser casting. With this form one valve can be placed on the top and one on each side, making five valves in all; thus with this arrangement, and the same

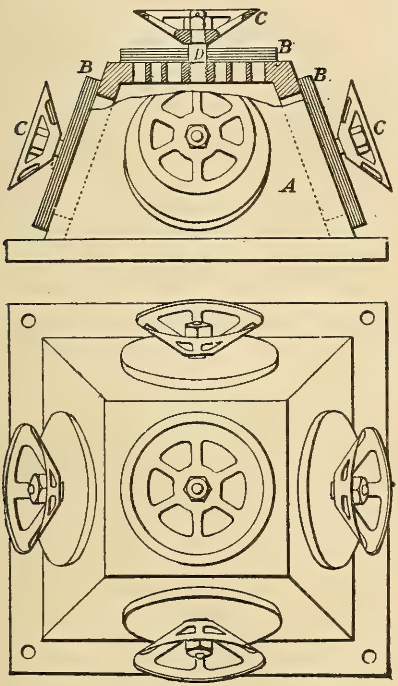


Fig. 322.—Box Valve Seat with sloping sides, arranged for five Valves for the Air Pumps.

A, Box with five valves. B B, India-rubber valves. C C, Guards. D, Stud for guard.

lift of valve as in the former examples, five times the area is obtained; or with excessively fast-going engines, the lift of valve can be reduced, a great desideratum even with india-rubber valves, for undoubtedly the wear and tear cannot be so great, while the area for the passage of the water is always greater than in a single valve. In another arrangement four valves are placed on the top of a square box, and two on each side, making twelve valves in all. These sets, and indeed all india-rubber valve arrangements, can be placed upside down, or at any angle that may be considered best for the free entrance and exit of the water from the air pumps. Instead of round valves, some makers cut the india rubber into oblong flaps, hinged at the centre and folding up against the guard on each side; by this means the holes for the bolts do not weaken the india rubber so much as when they are placed along the edge. The holes for the passages of the water are hexagonal, formed around circles 1 inch in diameter, with webs similar to a honeycomb. The area through the valves should be as large as possible, and the grated space equal to the length and breadth of the hole in the

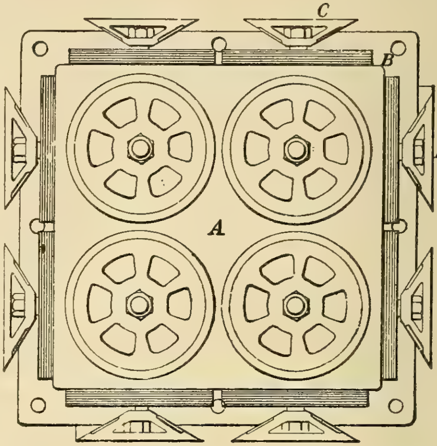


Fig. 323.—Box Valve Seat with square sides, arranged for twelve Valves for Air Pumps.

A, Box with twelve valves. B, India-rubber valve. C, Guards. D, Stud for guard.

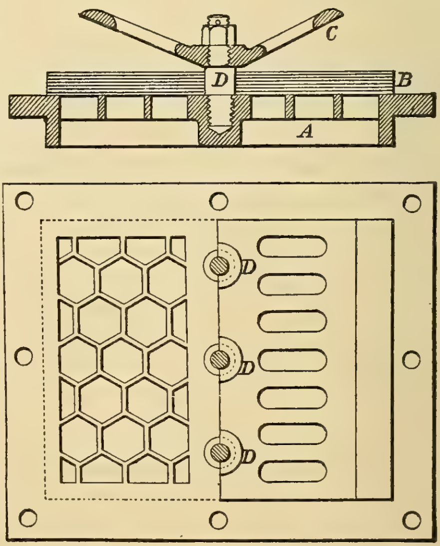


Fig. 324.—Double Oblong Valve with Hexagonal Grating for Air Pumps.

A, Grating. B, India-rubber valve. C, Guard. D D, Studs.

condenser, even although half-grated holes are cut in the pattern; they are bolted down with stud bolts and nuts, and collar bolts at the hinge for taking the flat guard, these bolts being screwed into holes bored and tapped in cross webs cast in the condenser for supporting the grated plate, because with the peculiar form of hexagonal holes it is not convenient to introduce strengthening ribs in the grating.

Discharge Valve.—We will now consider the arrangements

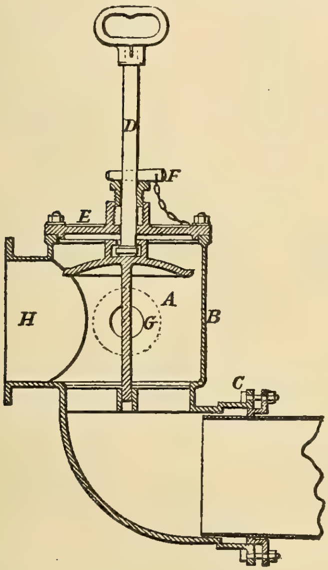


Fig. 325.—Brass Discharge Valve and Box for Discharge Pipe from Hot Well, fitted with Expansion Joint. — A, Valve. B, Chest. C, Stuffing box and gland. D, Lifting spindle. E, Cover. F, Cotter. G, Hole for donkey feed-valve box. H, Branch at side of ship.

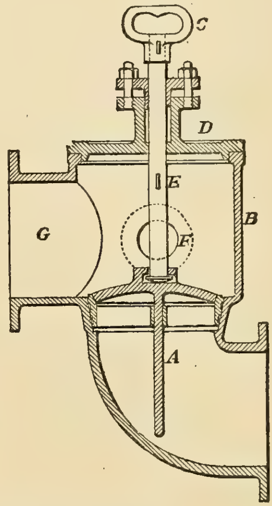


Fig. 326.—Brass Discharge Valve and Seat, with cast-iron Valve Chest for Discharge Pipes from Hot Well. — A, Valve. B, Chest. C, Lifting eye and spindle. D, Cover. E, Hole for cotter. F, Hole for donkey feed-valve box. G, Branch at side of ship.

required outside of the condenser. The discharge pipe from the hot well should be fitted with an expansion joint, placed on the valve chest at the ship's side; this valve is introduced so that the sea water can be shut off when the fittings inside of the condenser and air pump require inspection. The valve in most cases is a spindle one, with a long rod secured to the top, passing through a stuffing box on the valve-chest cover, and having a ring handle fitted at the top, for attaching a block and tackle for lifting it; and as the valve box is generally placed inside of the coal boxes, means

for lifting it from the orlop deck should be provided. In other examples the valve is coned, fitting into a seat turned out for its reception, the rod at the top being secured by a nut on the under side, and having a ring handle as before; when the valve is lifted up a flat key is driven through a slotted hole in the rod, the key rests on the top of the gland, and by this means the valve is held up. Hemp packing may be placed in a recess turned in the valve to insure its being perfectly water tight. A variety of forms of gridiron sluice valves have been introduced, each having a screwed spindle stepped at the bottom of the valve chest, and working in a nut on the back of the valve, passing through a stuffing box in the cover, and its end fitted with a handle. Outside of the stuffing box a collar is left on the rod, which is held down by this collar placed under a cross bar fitted to the cover with studs; thus when the handle is turned round, the nut and valves move up or down, opening the apertures or shutting off the sea water when the handle is turned the reverse way. For convenience in turning the handle, the valve chest should be placed outside of the coal boxes, and a strong pipe fitted between it and the ship's side. The valve chest may be of cast iron, but the valve and seat should be of brass, and the top spindle of Muntz metal. Sometimes large flap valves are used on the side of the ship; these are generally hung with a spindle at the top passing through the side of the box, and may be kept shut with a weighted lever on the end of the spindle: this plan has the advantage of the valve opening outwards, and should the engine be started with the valve shut, the pressure of the water in the discharge pipe would open it. Of course spindle and conical valves are likewise placed so that the discharged water forces them up; but sluice valves must

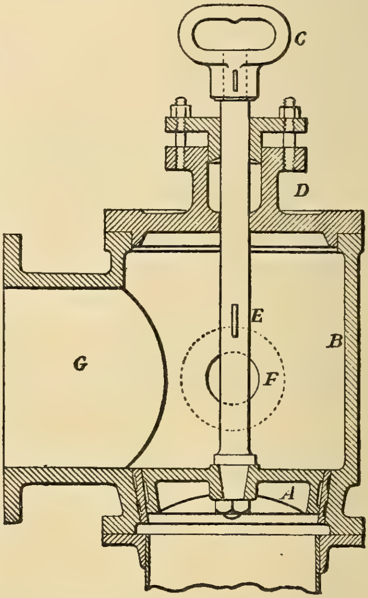


Fig. 327.—Conical Brass Valve and Seat, with cast-iron Valve Box for Discharge Pipes from Hot Well.

A, Valve. B, Chest. C, Lifting eye and spindle. D, Cover. E, Hole for cotter. F, Hole for donkey feed-valve box. G, Branch at side of ship.

be moved by hand before starting the engines, and in that respect they are not so safe as the spindle valves and other arrangements.

The *injection valve* is simply a sluice, placed in a suitable valve chest, which is bolted to the side of the condenser; the valve is of brass, sliding against a surface of the same material, let into the cast-iron valve box. The valve is provided with a Muntz-metal spindle, keyed through a boss cast on the back of the valve; at the top end of the spindle a slotted cross-head is fitted for the lifting lever to pass through, and which is generally arranged on the top of the condenser. Gridiron valves are sometimes used, which are moved by a spindle attached to the valve with an eye and pin passing through a snug cast on the back of the valve; with this arrangement it is advisable to cast the valve chest in brass, having a screwed packing nut at the top for the valve spindle, with a corresponding screw tapped or cut in the valve-chest cover. For engines of small power plug taps may be used, so arranged that the water comes in through a branch on the bottom side of the conical valve seat, and passes through a hollow plug, the bottom part of the cone being tapped for the reception of a screwed brass piece which is brazed on the tapered copper injection pipe. The top part of the plug is fitted with a packed gland, or a gland without

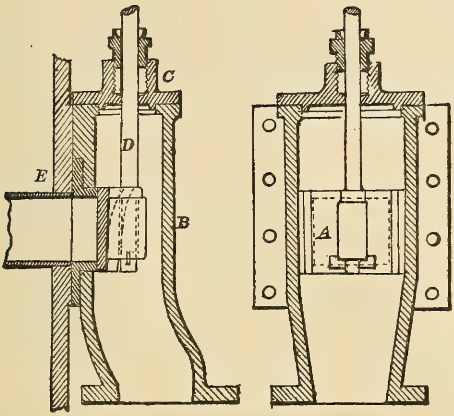


Fig. 328.—Sluice Injection Valve.

A, Sluice valve. B, Chest. C, Cover. D, Spindle. E, Condenser.

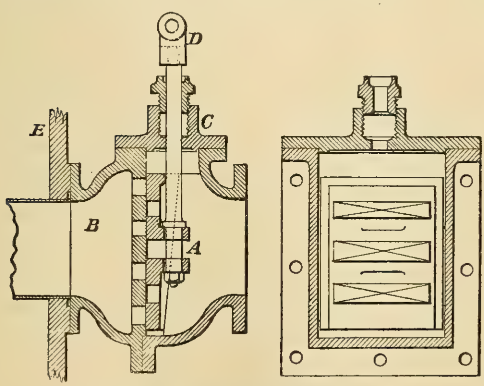


Fig. 329.—Gridiron Injection Valve.

A, Gridiron valve. B, Chest. C, Cover. D, Joint for lifting arm. E, Condenser.

packing may be used; this is introduced to keep the plug in its seat. A handle is keyed on the plug for moving by hand, or levers are arranged with rods passing along to the starting platform. The inside injection pipe is made of a conical form, tapering from the valve to the end; the apertures are placed so as to shower the water over a large surface in a way regulated by the form of the condenser. These apertures are bored out, or else cut across with a saw; the former plan may be named the jet system, the latter the sheet system, as the water then falls into the condenser in small sheets. The injection pipe is sometimes fitted with a longitudinal plate passing up the centre for one half of its length, by which the water after passing through the injection valve is divided into a top and bottom stream, with holes pierced in the pipe for each; but this is an unnecessary refinement, for the injection valve may be placed on the condenser, so that the internal pipe can have a branch on the middle of its length, and thus distribute the water right and left. This form of internal pipe should likewise taper from the middle to each end, so that the jets at the end may rush into the condenser with about as much force as those nearest the valve; for undoubtedly were the pipe made quite parallel, and pierced with the same number of apertures along its entire length, the pressure of the water would decrease at the extreme ends, owing to its escaping into the condenser, but the tapering of the pipe contracts the water along its entire length, and the pressure from the head of water outside of the ship is better maintained, consequently the water is showered over the condensing area more equally. It is necessary to support these inside injection pipes, as the weight of water is considerable; this can be done with a wrought-iron support, fastened to any of the ribs inside of the condenser.

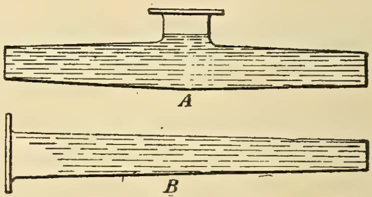


Fig. 330.—Inside Injection Pipes.
A, Injection pipe tapering toward ends.
B, Tapering injection pipe.

The *bilge injection valve* (Fig. 331) is fitted as low down in the condenser as may be deemed necessary, and consists of a spindle valve of brass fitting into a seat cast along with the valve chest, also of brass. The valve has a spindle on the top passing through a stuffing box in the cover; the top end of the spindle is screwed, and works through a brass bush secured in a cross bar, which is supported

with suitable studs let into the cover. On the end of the spindle a plain handle or small hand wheel is fitted, by which the valve is screwed up from and down on its seat. These valves are only used in the event of great leakage in the ship, the bilge water being then taken into the condenser, and pumped overboard as in the ordinary injection system. In order to keep foreign matter from entering the condenser, it is necessary to protect the pipe passing from the bilge injection valve down to the bottom of the ship with a box piece at the end, perforated with a number of small holes.

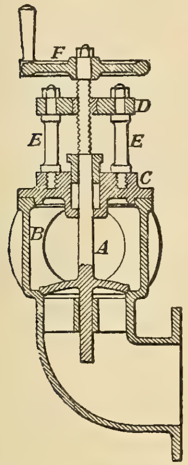


Fig. 331.—Bilge Injection Valve.—A, Spindle and valve. B, Chest. C, Cover. D, Crosshead. E E, Columns. F, Hand wheel.

The *snifting valve,* for blowing all the air and water out of the condenser previous to starting the engine, is placed at the lowest part of the condenser, on which a branch is cast for holding it. It is a spindle valve opening upwards, and is fitted with a baffle plate placed on the valve box, through which a thumb screw works in a screwed brass bush; by this means the valve is held down after the process of blowing through is completed, and indeed, when the vacuum is formed in the condenser, the atmospheric pressure comes instantly into operation, firmly closing the valve, which can then be secured by the thumb screw at leisure.

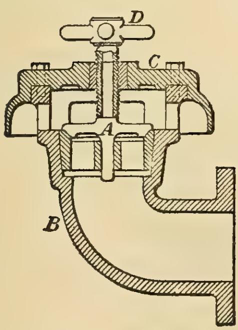


Fig. 332.—Snifting Valve. A, Valve. B, Chest. C, Cover. D, Set screw.

The *feed pump* is generally of the single-acting plunger type; the body of the pump is of cast iron, with a brass gland and bush at the bottom of the stuffing box; when bolted to the side of the condenser casting, the brass plunger is worked from an arm keyed on the piston rod, and has an inside rod of iron, by which the plunger can be disconnected while the engine is in motion. The disconnecting gear consists of a thumb screw pressing against a brass block let into the end of the pump ram, the inside rod being of sufficient length to work loosely in the hollow ram when the plunger is at the bottom of the stroke. When connecting the pump, the thumb screw should press lightly on the brass block until the plunger is pressed up

against a collar left on the rod (this must take place in the act of forcing the water), the ram is drawn outwards, and in the return stroke it slips or slides on the bush piece, until it is stopped with a collar on the rod, then the thumb screw can be tightened up. This simple contrivance is far superior to any other for disconnecting the plungers when the engine is in motion. Some makers prefer placing these pumps at the back of the condenser, fitting them to the platform on which the gearing is located for handling the engine, either above or below the centre line of motion of the piston and adjuncts; with the former arrangement the plunger is connected to a stud placed on the top of the crosshead arm for taking the piston rods, and in some cases is worked directly from a prolongation of the air-pump rod, which passes through a stuffing box at the back of the air-pump cover. Piston pumps are sometimes used with advantage, the brass cylinder in which the solid or packed piston works being let into a part of the condenser casting, and generally worked directly off the steam piston, in the same manner as the air-pump piston; with this arrangement the pump is double acting, one end being used for the feed and the other for the bilge pump. The latter, in other arrangements, is exactly similar to the feed-pump barrel, and is placed on the condenser on the opposite side of the centre line of crosshead from that of the feed pump, and can be worked off an arm keyed on the piston rod; or when it is fitted to the starting platform at the back of the condensers, it is connected to the bottom arm of the crosshead in a similar way to that of the feed pump. Many prefer the pump arrangements fitted to the condenser, as the labour of fitting up is thereby greatly reduced, and the engine as a whole rendered more compact.

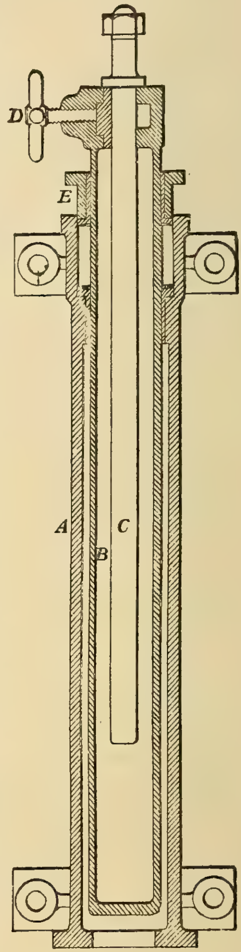


Fig. 333.—Feed and Bilge Pump. A, Pump. B, Ram. C, Inside rod. D, Thumb screw. E, Stuffing box and gland.

The valve box for the feed pump is of brass, and is generally

placed at the end of the pump; the feed or delivery and the relief valves are placed on the same level, while the suction valve is immediately under the relief valve, which is fitted with a spiral spring compressed by a set screw working in the top of a brass bow placed over the spring; the pressure on the valve should be a little in excess of the steam pressure in the boiler. The sole use of this valve is to allow the water in the pump to escape into the hot well when the feed regulating valve on the boiler is shut; a branch is cast on the relief-valve box, with a pipe leading into the chamber above the head valves, by which the water when not required in the boiler is returned and finds its way overboard. A plug valve for shutting off the suction is also fitted to the valve box; this is used for shutting off the water in the event of any of the pump valves requiring inspection, and may be used for stopping the supply to the pumps, in

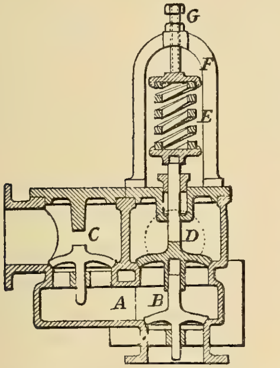


Fig. 334.—Valve Box for Feed Pump.

A, Valve box. B, Suction valve. C, Delivery valve. D, Relief valve. E, Spring. F, Bow. G, Set screw.

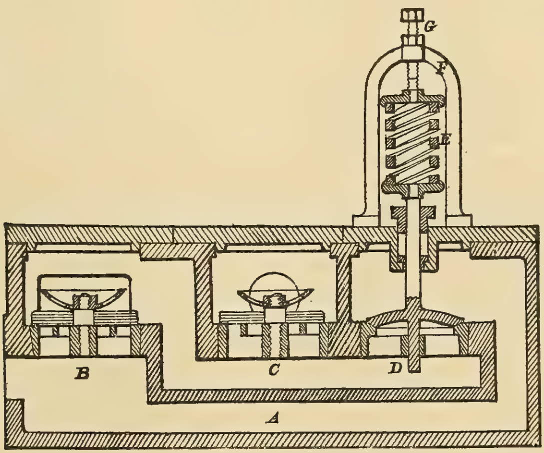


Fig. 335.—Valve Box for Feed Pump.

A, Valve box. B, Suction valve. C, Delivery valve. D, Relief valve. E, Spring. F, Bow. G, Set screw.

which case the plungers may be kept working, although no water can be forced into the boiler or through the relief valve. India-

rubber valves are sometimes used for the feed pump, having conical brass seats grated in the casting, and let into a cast-iron valve box containing the suction, discharge, and relief valves, the latter being a brass valve fitted with a spring in the usual manner. All the valves may be placed on the same level; the suction at one end of the valve box, the discharge in the middle, and the escape at the other end, with a passage leading underneath the discharge and escape valves from the top of the suction valve, and a lower return passage from above the escape in connection with the suction pipe or hot well. In some instances suction and discharge valves only are fitted, with a separate relief valve placed on some other part of the feed pipe. A similar arrangement of valves is required for the bilge pump, but of course a relief valve is not needed, as the bilge water is pumped directly overboard, and a non-return valve placed on the ship's side. The india-rubber valves are used to prevent the disagreeable noise caused by brass valves beating sixty or more times in the minute. To obviate this evil wooden rings have been recessed into the valve with advantage. Perhaps the best plan of doing this would be the Cornish one of recessing the wood into the valve seating, in the same way as for large double-beat valves for the pumps in deep mines. The valves in this case would be discs turned on the face, with central holes for working on spindles; thus the valves are guided by this means, necessitating a central boss with wood-bearing surface. Of course the valves can be of the spindle type, working through and guided by holes bored in the bosses cast along with the valve seats. An air vessel should be placed on the feed-pump valve box, or on some part of the feed pipe between the boiler and the top of the discharge valve, by which any sudden strain caused by the passage of the water through the pipes is greatly neutralized, and the discharge into the boiler is rendered more equal.

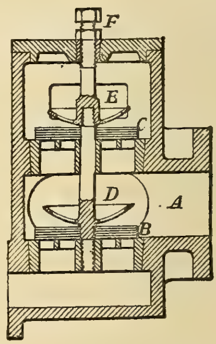


Fig. 336.—Valve Box for Bilge Pump.

A, Valve box. B, Suction valve. C, Delivery valve. D, Guard with holding-down spindle. E, Guard. F, Set screw.

The *hand pump* (Fig. 337) is an additional one, which can be worked either by hand, or if required connected to the engine. Its duty is somewhat complicated, as it must be fitted to draw water from the boiler, from the bilge, and from the sea; while the discharge pipes

must be arranged to pump water into the boilers, on deck, and overboard. The most convenient form for this pump is the plunger type. It is generally placed vertically at the end of the cranked shaft, the body of the pump being bolted down to the engine keelson; sometimes it is placed horizontally, and is fitted to the condenser, fitting strips and joggles being cast on the parts for its reception. The trunk plunger is actuated by a pin and rod; the pin is fitted to the end of the cranked shaft, and has a rod with a plain brass bush, working in a hollow plunger rod attached to a pin passing through a joint at the bottom of the plunger; this hollow rod has a thumb screw and brass block at the top for throwing into gear or disengaging the pump. When working free, the inside rod merely moves up and down in the hollow brass piece, which vibrates along with the rod as the crank pin revolves; when the pump is required, with the engine in motion, a cotter is driven through a slot in the brass rod, and forms the stop for the inside rod butting against, which it does gently by means of the thumb screw and friction block, as with the feed pumps; the thumb screw is then tightened up and the connection is complete. For working the pump by hand, a bracket is cast along with the body of the pump, on which a lever is fitted, and flat side rods are connected to the pin at the bottom of the plunger, while the lever has a part forged along with it for the reception of a long handle. When the inside rod is disengaged, and when the engine is not going, or even were it in motion, the pump can be thus worked by hand, the hollow brass rod merely sliding on the wrought-iron one inside. Of course when the pump is worked by the engine, the hand lever and connection vibrate with the motion, it is therefore imperative that the handle should be disengaged from the pump lever, a socket being

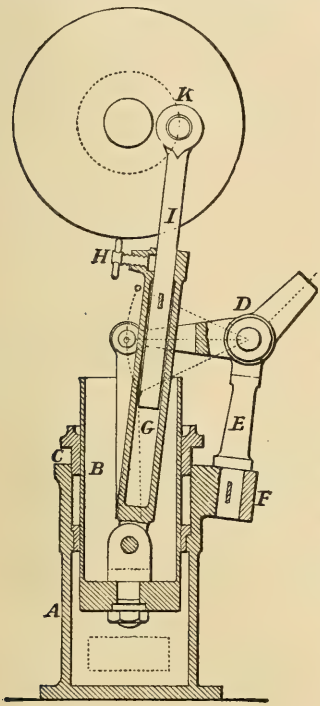


Fig. 337.—Hand Pump.

A, Pump. B, Plunger. C, Stuffing box and gland. D, Hand lever with side connecting rods. E, Stud. F, Snug for stud. G, Hollow rod. H, Thumb screw. I, Connecting rod. K, Crank pin on the end of shaft

forged on it for that purpose. The pin on the end of the cranked shaft is forged on a flat ring, which is accurately turned, and bolted to the end of the main shaft, a projection being left on the shaft for its reception. Some makers connect the pump by means of a plain rod, having a sliding block fitted with a pin, working in a guide formed on the disc that is bolted to the end of the cranked shaft; this block and pin is moved by a screw and thumb handle, by which means the stroke can be varied to any extent within the full throw, and even brought to the centre of the shaft, thus imparting no motion whatever to the pump ram. This is certainly a very simple means for disconnecting the pump, but at the same time no provision is made for working it by hand, which is the chief thing to be studied in these pump arrangements.

The valves are generally metallic, or india-rubber discs may be used, and at the bottom of the pump an escape valve is fitted loaded with a lead weight. This latter valve is required, as there are many valves on the delivery pipe which may be shut when the engine is started, or even close when it is in motion, due notice of which will be given by the water being ejected through the escape valve. The end of the suction pipe passing down to the bilges must have a box perforated with small holes to prevent foreign matter entering the pump.

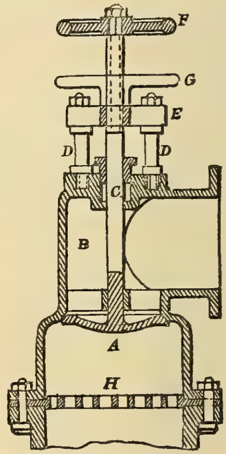


Fig. 338.—Kingston Valve.
A, Spindle and valve. B, Chest. C, Stuffing box. D D, Columns. E, Crosshead. F, Hand wheel. G, Thumb screw. H, Grating.

Kingston valves.—Kingston valves must be fitted to the pipes for injection, feed, and blow-off for the boiler, steam pump, &c., and indeed to all pipes passing through the bottom of the ship. The arrangement here is similar to that for the oscillating engine already described; strong cast-iron branches being placed at the ship's side for preventing the rapid deterioration of the wrought-iron plates by the galvanic action of the two metals—brass and wrought iron—in juxtaposition, assisted greatly by the adjoining copper pipes. In preference to the Kingston, some use spindle valves, fitted with a screw on the spindle working into a nut in the cross piece, having a jam thumb screw fitted on the top of the crosshead.

The various arrangements of hand wheels for starting, reversing,

and stopping the engines are given in another part of this Work (see page 110).

The usual *hand gear* for the blow-through, injection, throttle valve, blow-off valve from cylinder, and all the other necessary handles, should be arranged on the same platform. We prefer this platform to be on the same level as the engine-room floor plates, but some engineers place it on the top of the condenser; and certainly in this position the engineer commands a better view of the machinery, but his duties when the ship is under steam lying between the engine and the boiler rooms, the hand gear should be placed in such a position that it can be reached at a moment's notice, and as near the main starting wheel governing the link motion for actuating the steam valves as convenient. The blow-through, injection, and throttle valve handles should be placed in a

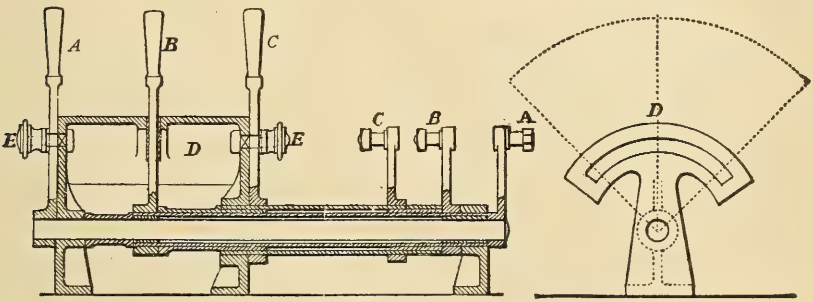


Fig. 339.—Hand Gear.

A, Injection handle and lever. B, Blow-through handle and lever. C, Throttle handle and lever. D, Sectors. E E, Thumb screws.

row. Some arrangements have a central rod for the injection valve, a hollow tube with levers for the blow-through placed over it, and another over this for the throttle. When thus arranged the rods cannot be connected directly to the various valves, but the line of motion can be conveniently changed by small sector wheels cast in brass, and bevelled to suit the requirements; in other cases short levers are keyed on the ends of the inside rod and to the outside tubes, and fitted with pins and rods for changing the direction of the motion.

Having considered the main details necessary in the manufacture of the direct-action horizontal marine engine, we will now notice the means to be adopted for effecting a thorough *lubrication* of all the moving parts in the machinery. The main bearings are those

most important, and their friction can always be reduced to the minimum by giving them ample rubbing surface,—this, combined with good material and first-class workmanship, being essential in all engines, more especially in those of great power, encountering permanent loads, and working at a high velocity. Lubricators should not be too elaborate in design; in their construction plainness and efficiency should rather be aimed at. The oil cups placed on the main bearings are cast in brass, with covers and oil pipes for siphon wicks; they should be divided into two compartments, one for the oil and another having a plain hole bored down through the brasses, for water lubrication in the event of the bearings becoming hot. To effect this properly a pipe is carried across the engine directly over the main bearings, and supported with standards of wrought iron secured to the main framing. This pipe is provided with plug taps and water distributors for each main bearing and crank pin; it also carries oil cups with long siphon pipes for lubricating the crank pins, the wick hanging down a very little past the end of the pipe. The water enters from the sea directly, a branch pipe being cast on one of the Kingston valves, and an ample flow is obtained for showering over the bearings in the case of violent heating. Sometimes the standards for carrying the water pipe placed over the main bearings are hollow pipes jointed on the top of the framing, and provided with a valve at the bottom, one pipe standard being placed on each frame; thus each bearing can be supplied with water independently. The pipe at the top has coupling joints with nuts, or simple flange joints may be adopted; on the standard pipe nearest the Kingston valve a branch is cast, for connecting the supply pipe to the Kingston, and a plug tap is generally fitted to one of the standards, with means of attaching a flexible pipe to it, for showering water over any other part of the engine. The connecting rods have cups fitted on, with covers having raised pipes and tongue pieces, for licking off the oil from the siphon wicks suspended from the oil cup fitted overhead; by this means the crank pin is thoroughly supplied at each revolution of the cranked shaft. All the other lubricators for the engine consist of cups cast in brass, fitted with inside pipes and siphon wicks, and fastened to the various parts in such a way that they can be removed when they require to be cleaned. Many journal bearings have cups cast on, and plain holes bored through; this plan is preferable to that of merely boring a countersunk hole in the journal

brackets, into which the oil cannot be poured steadily, and generally runs over on the machinery, whereas in the former plan the oil is poured into the small oil cup and is beneficially used. The tallow cups for lubricating the slide valve, cylinder, and pistons are similar to those in general use, which have been already explained in treating of the oscillating engine.

Turning gear.—When the vessel is in port, with the steam down, it is necessary to turn the engines daily by hand, so as to change the relative position of the working parts, and prevent the furrowing induced by the galvanic action resulting from the contact of the wrought-iron piston rods and brass glands, as well as to facilitate the adjustment of the slide valves or any other part of the machinery. The arrangement for doing so consists of a worm working into a wheel fitted to the end of the cranked shaft, which has a cast-iron coupling for bolting it to the boss or coupling cast on the wheel; the worm wheel being thrown in and out with suitable mechanism. Some makers simply key up the worm-shaft bearings, which work in blocks fitted to a cast-iron guide plate, arranged across the line of the lying shafting; others place the worm wheel vertically at the side of the turning wheel, and draw out the bottom bush on which the worm shaft is stepped, by means of a small hand screw and wheel working through a brass bush cast on the plate the bush rests on, the top part of the shaft being supported by a bracket bolted to some part of the engine-room bulkhead. Some engineers adopt an eccentric motion similar to the back motion of a turning lathe, as a means of putting the worm wheel in and out

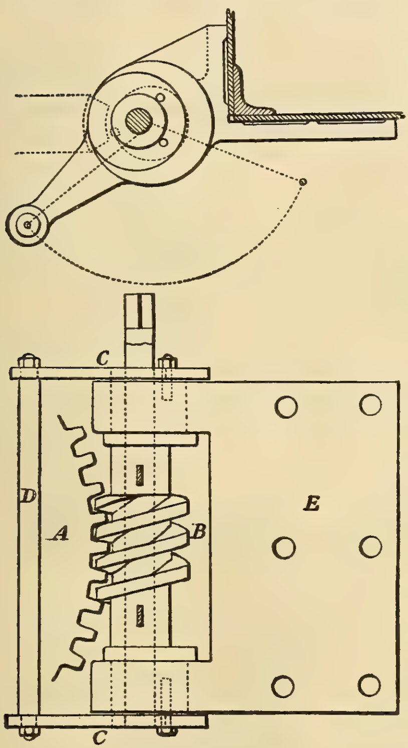


Fig. 340.—Turning Gear.

A, Worm wheel. B, Worm pinion. C C, Eccentrics. D, Handle connecting the eccentric arms. E, Plate for bolting to the bulkhead.

of gear. A square part is formed on the end of the worm-wheel shaft, to receive a ratchet brace lever, fitted with a double paul to work either way, and a part is left on the lever to receive the socket formed on the long hand lever, on the end of which is forged an eye for securing a rope, which can be taken to any part, so that a number of hands can be employed in turning the engine—a needful provision as the back of the engine space is generally confined.

BOILER FITTINGS.

Safety valve.—Amongst the boiler fittings the most important is the safety valve. In river steamers there are generally two valves fitted to each boiler, placed in one valve chest, with the waste-steam pipe between them. The valves and seatings are of brass; a spindle of wrought iron is fitted to the top of the valve, passing through a cover on the valve chest, and is fitted with an eye on the outside. This eye is arranged so as to turn round the valve with a hand bar, to prevent it becoming fast on its seat. The valve is loaded with a certain weight placed in the valve chest above the valve; and on the outside of the casing flat discs of cast iron are placed on the spindle, or taken off, as the steam is raised above the usual working pressure, or is blown off by the waste pipe. The waste-steam pipe is of copper, fitted with a gland and stuffing box, cast on the valve chest; and there is a small branch at the bottom of the chest for running off the water accumulating from the condensation of the waste steam. This water is generally collected in a tank fitted to the side of the vessel, and is used for cooking purposes, being an all-important fresh-water supply for ocean steam ships.

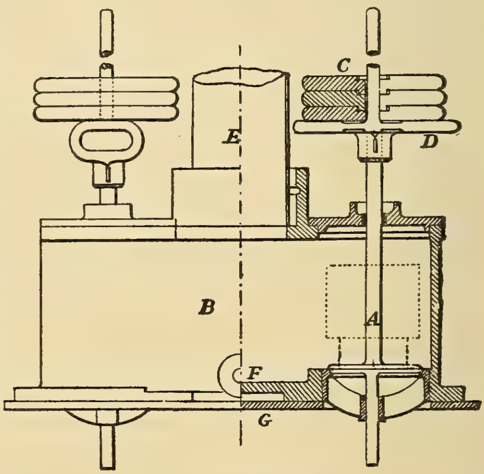


Fig. 341.—Safety Valve.

A, Valve and spindle. B, Chest. C, Weights. D, Turning handle. E, Waste-steam pipe. F, Hole for running off the condensed steam. G, Boiler.

The safety valves for such ships differ materially from those of river steamers, inasmuch as the weights are placed entirely in the valve chest above the valves, or else inside of the boiler; the latter method requiring a long spindle and socket connected to the valve spindle. In the former method the valve-chest covers are under lock and key, and in the latter the weights cannot be got at; the valves cannot therefore be tampered with, or the boilers subjected to undue pressure. Two safety valves are fitted to each boiler, placed in one valve chest, with a branch cast on for the horizontal copper pipes passing along to the branch pipe for the vertical waste-steam funnel; this branch is fitted with a stuffing box and gland, to allow for the expansion of the copper pipes. The main waste-steam pipe is fitted to a flange on the top of the central branch box, which is made of cast iron, having a small branch at the bottom for running off the water derived from the condensation of the waste steam in the act of blowing off from undue pressure or otherwise. The valves are lifted by a lever arrangement, having a spindle within the valve chest; this lever is carried along to any convenient position, and supported by a bracket at the end, which is bolted to the top of the boiler; a long lever handle or other arrangement is fitted at the end of the shaft, with a quadrant fitted to the boiler, and drilled with a number of holes; a small pin is provided, connected to a fine chain to prevent it being lost. By this means the valves can be raised their full lift, or only a very small part, as may be desired, and held in position by passing the pin through the quadrant and lever handle. When the weights are inside of the boiler, the spindle for supporting them has a pin

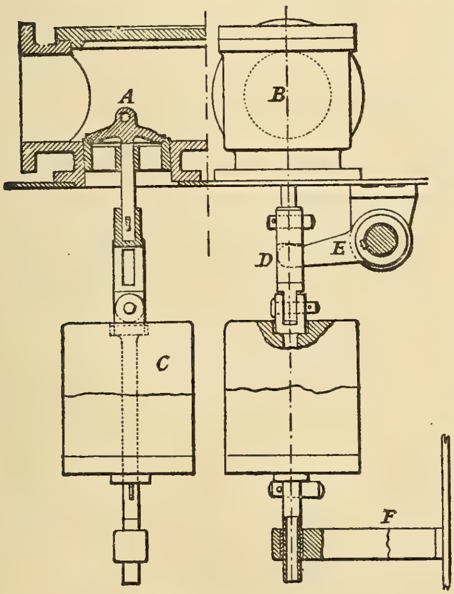


Fig. 342.—Safety Valve.

A, Valve. B, Chest. C, Weights. D, Slot rod for lifting arm. E, Lifting arm. F, Guide.

joint connected to a collar brass connecting piece, which is cottered to the valve spindle, the forked lifting arms of wrought iron work loosely on the collar, and the shaft is bracketed at the one end from the crown of the boiler, and at the other end it passes through a stuffing box with gland, fitted to the front plate of the boiler; the shaft being fitted with a lever handle and quadrant, or any other suitable appliance, such as a worm wheel and toothed quadrant on the shaft, with a turning handle and bracket fitted to the worm spindle.

In all arrangements for lifting the valves it is imperative that their free action should not be interfered with; at any position of the lifting levers, the valves when acted on by the steam pressure must lift solely by that pressure, as the lever handles are only arranged to lift the valves in the act of blowing out the boilers or easing them when the engine is not at work. It is also essential that all the rubbing parts should be bushed with brass to prevent corrosion: this is a most important point, for where the free action of the levers and shaft is not perfect, accidents may occur, which due attention to their fittings will alone prevent. In order that the surfaces of the valves may be changed occasionally, the covers are fitted with hollow guides for the ends of the spindles,—that is, when the weights are contained in the valve chests; the chests are removed, when the spindle can be gripped and the weights and valves turned slightly round. When the weights are placed inside of the boiler, the valve-casing covers can be removed, and the valves turned with a key or spanner, by means of a projecting square piece cast on the top of each valve. Many arrangements do not allow of this being done,—for instance, when the lifting arms work in slotted connections, as is sometimes the case when the weights are inside of the boiler; but all lifting arms should be forked, lifting the valves and weight by working on a collar formed on the weight spindle. For inside-weighted valves the spindle must be guided at the bottom through brass bushes on the spindle and guiding piece fitted to the boiler. (See page 462.)

The *steam stop valve* is simply a spindle one, generally lying on its side, fitted with a brass seating, placed in a cast-iron valve chest, having a branch cast on above the valve for the pipe connections. Where two valves are used, one of these branches has a plain flange, and the branch on the other valve chest is fitted with an expansion joint. On the top of the valve is cast a part for taking the head of

the lifting spindle, in which it can freely revolve; the spindle passes through a stuffing box on the casing cover, with a gland for pressing down the packing; between the valve and the bottom part of the stuffing box a screwed part is turned on the spindle, working in a brass nut let into the bottom part of the stuffing box. A handle is fitted to the spindle, and when it can be conveniently reached is quite close to the gland; but when the valve box is placed beyond reach of the attendant, the spindle is prolonged by a wrought-iron connecting piece, fitted with a socket for taking the brass valve spindle, and a wrought-iron bracket is fitted to the casing cover. The valve chest in those instances is placed vertically and inverted, so as to be worked from the boiler-room floor plates, which is decidedly the most convenient position for turning round the handle for opening and shutting the valve. A small branch is generally cast on one of the stop-valve chests between the boiler and the valve, for fitting the small stop valve in connection with the auxiliary steam pump, by this means saving an extra hole in the boiler plates. Of course the position of the steam pump must be fixed in the engine room, and the branch cast on the stop valve nearest to it, thus effecting a saving in piping, which would not be the case if, for instance, the steam pump was arranged on the starboard, while the small stop valve was fitted to the larboard main stop valve, as the case may be. The stop valve for the auxiliary steam pump should in no instance be fitted to the steam pipes, but connected directly to the steam space in the boiler, so that it can be wrought independently even although the main stop valve is closed.

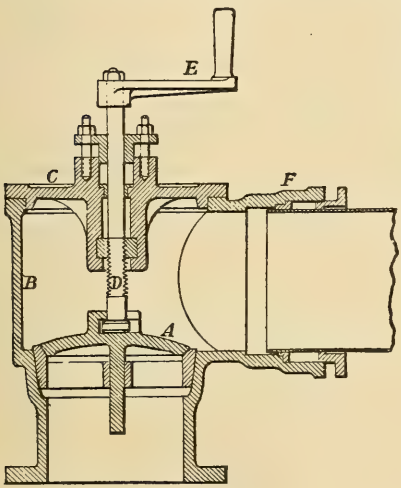


Fig. 343.—Stop Valve.

A, Valve. B, Chest. C, Cover. D, Screwed spindle. E, Handle. F, Stuffing box and gland.

The *branch steam pipe* between the stop valves and the engine must be arranged to suit the number of boilers; where two boilers are used, the main pipe branch should be larger than the branches from the boilers. These branch pieces are fitted with expansion

stuffing boxes and glands, to suit the direction of the expansion and contraction of the copper pipes. In all bends care must be taken to fit a collar on the end of the pipe, the gland and bottom

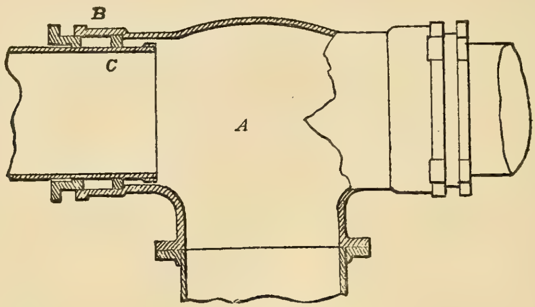


Fig. 344.—Branch Steam Pipe.

A, Branch pipe. B, Stuffing box and gland. C, Loose bush.

bush being first placed on the pipe; this precaution is necessary, as bends under pressure have a tendency to assume a straight line, and fatal accidents have occurred from the steam by its reactive force blowing out the bend and filling the engine room direct from the boiler.

Clothing the steam pipes.—In order to prevent condensation taking place in the passage of the steam to the cylinder, all the steam pipes should be carefully clothed with felt, secured with fine wire wound round the pipe, and covered over all with canvas sewn tightly on, which should receive two or three coats of paint. In some instances the pipes are lagged with wood, and secured with neat brass hoops.

Separator.—Some makers fit a moisture separator to the steam pipes. This appliance acts by abruptly changing the flow of the steam, and is similar to those used for land engines, which have been explained in a former part of this Work. By this means much of the moisture is got rid of, trickling down the baffle plate to the bottom of the separator, and then run off by a valve into the bilges, or used for washing and cooking purposes.

Covering the boilers.—To prevent radiation, and consequently waste of fuel, the boilers are lagged in all available parts. This form of lagging consists in fastening square pieces of wood at the corners and at intermediate distances on the boiler, the wood being fastened by small stud bolts and nuts; felt is then laid in between

the wooden battens, flush with the top of the wood, and the lagging or strips of wood, which are grooved and feathered, is then laid on, and securely fastened to the battens with screw nails. The wood is then painted all over, and on the top of the boiler and round the top corners thin sheet lead is laid, which thoroughly protects the top of the boiler plates from the moisture that lodges on the lagging, and would run between the joints were the lead not forming an effectual waterproof covering. This covering also keeps the boiler room comparatively cool. In many examples, however, with dry uptakes, as fitted to high-pressure boilers, lagging cannot be used, because it would ignite and smoulder away; in these cases the boiler room is kept cool by air spaces formed with thin plates placed in front of the uptakes, by which a current of air is continually flowing up between the uptakes and the plates, and prevents in a great measure the radiation of heat affecting the attendants.

Check valve.—The valves fitted to the boiler at the end of the feed pipes, termed the check valves, are spindle valves, contained in

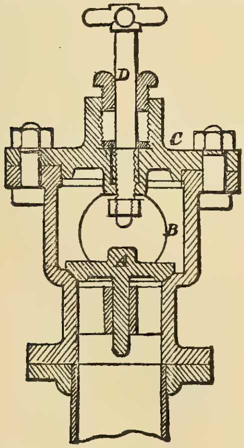


Fig. 345.—Check Valve.

A, Valve. B, Chest. C, Cover. D, Set screw.

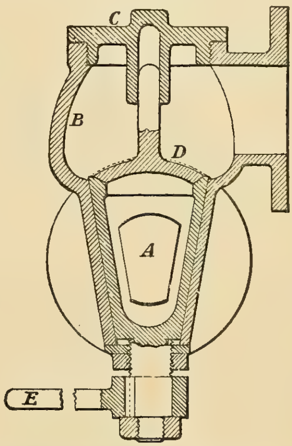


Fig. 346.—Check Valve and Plug Valve, &c.

A, Plug valve. B, Chest. C, Screwed cover. D, Check valve. E, Handle.

brass valve boxes; the seating is turned in the box, and the valve ground in, having a separate screwed hand spindle passing through a stuffing box on the cover. By this means, when no water is required in the boiler, the spindle is screwed down hard on the top of the valve, the water passing through the pumps, escaping by the relief valve into the hot well. This valve on the boiler also

acts as a non-return valve, easing as it were the pipes at each return stroke of the pump, and in the event of any of the feed pipes giving way the valve of course instantly shuts with the steam pressure, and thus prevents an escape of hot water and steam into the boiler room: in this respect it may be termed the non-return safety valve. In some examples a plug valve has been fitted in connection with the non-return valve box. This is a refinement, however, which has not come into general use; ground plug valves are at the best very imperfect, and give a great deal of trouble to keep them in thorough working order. It will be seen in Fig. 346 that there is a handle secured to the plug at the bottom, which is hollow; and the non-return valve is fitted to the top of the plug, and guided by a spindle passing upwards through a hollow tube bored in the cover.

The *gauge glass* for indicating the height of water in the boiler is fitted to brass connecting pieces having a screwed packing gland, with plug tap at the top, and two taps in the bottom connection, screwed into a separate pipe, on which bosses are cast for that purpose; there are also three separate test taps fitted to the side of the pipe; these are required, as the gauge, although protected with a shield, sometimes breaks, in which case its plug taps are shut, and the attendant ascertains by opening the side taps if there is a sufficient quantity of water in the boiler. These taps have funnels and small pipes for blowing the water down into the bilge. The taps on the glass gauge should be so arranged on the branch screwed into the large pipe, that when they are shut a nut on the top of the connection can be unscrewed, and a new glass fitted without disturbing the joints. Plugs have sometimes been fitted in the connection in a line with the glass gauge, but such an arrangement is not quite convenient when a tube requires refitting; for, in the former plan the nut at the top being unscrewed the glass tube is put in vertically, whereas in the latter the nut requires to be edged in, and consequently does not fit so nicely; and the only saving effected is the small test tap placed at the bottom, although some makers fit two taps at the bottom, one over the other—an arrangement not at all required. It is preferable to cast the pipe which carries the gauge glass and test taps in brass, or a copper pipe may be used, with bosses brazed on for screwing the connection to. As the small taps are liable to get choked with deposit, they should be always so arranged with a nut on the connection which can be unscrewed, and a small rod pushed through to clear away the deposit.

Scum taps are fitted in connection with an internal pipe, for collecting the froth or scum at about the level of the water in the boiler, and a copper pipe is connected to the tap for blowing the dirty water overboard. The usual blow-off cock is fitted to the bottom of the boiler, with pipe connection and expansion joints on the blow-off Kingston valves, which is fitted to a strong cast-iron pipe at the bottom of the vessel.

Vacuum valve.—In the event of the steam in the boiler falling below the atmospheric pressure—or a partial vacuum being formed—a reverse valve is fitted to the boiler. It is of the spindle kind, nicely ground into its seat formed in the brass valve box. The steam acts on the top of the valve, while the bottom is open to the atmosphere; thus when a partial vacuum is formed in the boiler the atmospheric pressure lifts the valve, and the vacuum is at once destroyed, consequently the flat sides of the boiler have no tendency to collapse.

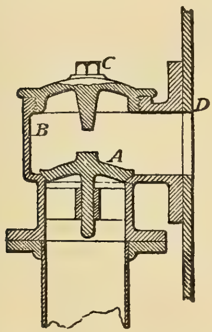


Fig. 347.—Vacuum Valve.

A, Valve. B, Chest. C, Screw cover. D, Boiler.

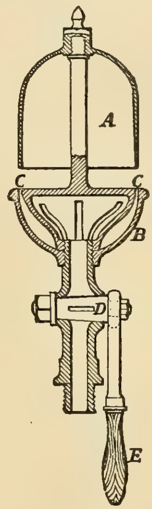


Fig. 348.—Whistle.

A, Bell. B, Bottom piece. C C, Annular space. D, Plug tap. E, Handle.

Steam whistles should be fitted to all vessels, for use in foggy weather. They are generally placed on the bridge, with a pipe connection to the boiler; and are formed exactly like the steam whistle for the locomotive engine. The depth of the bell varies to suit the note desired; but a deep bell, producing a full note similar to the guard's alarm on the railway engine, is desirable for ocean steam ships.

The following is an extract from a Report on Safety Valves, drawn up by a committee of the Institution of Engineers and Shipbuilders in Scotland,[1] which presents the various features of the question of area and method of loading in a succinct form:—

"SAFETY VALVE OPENINGS.—Since an orifice, with a square-edged entrance, reduces the flow from 12 to 14 per cent., this allowance will require to be made in computing the requisite area, and opening of a safety valve, which cannot be considered as presenting a much better entrance to the steam than a square-edged orifice. In making this 14 per cent. allowance the weight in pounds of steam discharged per minute per square inch of opening, with square-edged entrance, corresponds very nearly with three-fourths of the absolute pressure in the boiler as long as that pressure is not less than 25·37 lbs. Examples of this are shown in the following table:—

Absolute Pressure in lbs. per Square Inch.	Weight Discharged per Square Inch of Orifice, with Rounded Entrance, per Minute.	Weight Discharged per Minute with Square-edged Orifice.	Three-fourths of Absolute Pressure.
p_1.	w_r.	w_s.	$\frac{3}{4} p_1$.
25·37	22·81	19·6	19
30	26·84	23	22·5
40	35·48	30·5	30
45	39·78	34·2	33·8
50	44·06	37·9	37·5
60	52·59	45·2	45
70	61·07	52·5	52·5
75	65·30	56·1	56·2
90	77·94	67	67·5
100	86·34	74·3	75

The area of opening, requisite to the discharge of any given constant weight of steam, it will be observed, is very nearly in the inverse ratio of the pressure. Thus, while 3 square inches of opening, with square-edged entrance, will discharge $3 \times 23 = 69$ lbs. weight of 30 lbs. pressure steam per minute, one square inch of opening will discharge 67 lbs. per minute of 90 lbs. pressure steam.

The quantity of heat, however, requisite to generate (from water at 100°) 67 lbs. weight of steam, at 90 lbs. pressure, is only 1 per cent. less than is required to evaporate 69 lbs. at 30 lbs. pressure.

The boiler which will generate 69 lbs. of steam per minute at 30 lbs. cannot, therefore, possibly generate more than 67·7 lbs. at a pressure of 90 lbs.; but many experiments on record seem to indicate that the deficiency at the higher pressure is more than *ten per cent.*

[1] See Trans. of that Institution, vol. xviii.

In ordinary marine practice there is not often more than 20 lbs. of coal consumed per hour per square foot of fire grate, and the water evaporated seldom exceeds 9 lbs. per lb. of coal, which corresponds to 180 lbs. per hour, or an evaporation of 3 lbs. per minute per square foot of fire grate. Under those conditions the area of opening requisite to discharge all the steam a boiler can generate corresponds to four times the square feet of fire grate, divided by the absolute pressure; or, let a denote the area of orifice in square inches, and p_1 the absolute pressure—

$$a = \frac{4 \times \text{square feet of fire grate}}{p_1}.$$

The Board of Trade allowance is half of one square inch area of safety valve for each square foot of fire grate. Hence, the lift of valve is proportional to the diameter, and inversely as the pressure. For a discharge of 3 lbs. per minute per square foot of fire grate the requisite lift in inches is twice the diameter of a (flat-faced) valve, divided by the absolute pressure; this, however, does not apply to pressures less than 25 lbs.

Take, for example, a valve 5 inches in diameter, 19·6 square inches in area, which corresponds to $2 \times 19{\cdot}6 = 39{\cdot}2$ square feet of fire grate, which would evaporate $39{\cdot}2 \times 3 = 117{\cdot}6$ lbs. of water per minute. Then since the area a in square inches, requisite to discharge any weight, w in lbs. of steam per minute at the pressure p_1 is—

$$a = \frac{4w}{3p},$$

we would have, by taking the pressure $p = 60$, and the weight $w = 117{\cdot}6$, the area

$$a = \frac{4 \times 117{\cdot}6}{3 \times 60} = 2{\cdot}61 \text{ square inches,}$$

which corresponds to the opening of a flat-faced valve, 5 inches diameter, when lifting $\frac{2 \times 5}{60} = {\cdot}1667$ inches.

The circumference of a 5-inch valve being 15·7 inches and $15{\cdot}7 \times {\cdot}1667 = 2{\cdot}61$ square inches of opening, as stated.

When the angle of seat of valve is 45°, the lift required in inches is—

$$\frac{2{\cdot}8 \times \text{diameter of valve}}{p_1}.$$

When a boiler is regularly fired, and all the steam generated discharged through an ordinary safety valve, under a succession of

different pressures, the lift of valve, multiplied by those absolute pressures, should be a constant quantity, provided the same quantity of heat is constantly entering the boiler, and provided also that the absolute pressure in the boiler or pipe below the valve is not less than 1·726 times the absolute pressure of the steam in the chamber above the valve.

In actual experiment a deficiency is generally manifested at the higher pressures. Hence the suspicion of some considerable loss of heat at the higher temperatures.

It has been suggested that this might be accounted for by the low-pressure steam carrying water along with it—retarding its motion—and thereby requiring a larger opening; but this would only aggravate the case, since the same opening will permit of a much larger quantity of *heat* being discharged from the boiler with wet than with dry steam. This phenomenon may be suggested as one worthy of further investigation.

According to the Prussian law, as taken from *Engineering* of December 6th, 1872, and allowing 30 square feet of heating surface per square foot of fire grate, the area of safety valve is—

$$\frac{36 \times \text{square feet of fire grate}}{p}.$$

A valve of this size, when full open, is capable of carrying away nine times the quantity of steam generated at the pressure p_1, and therefore will, at the designed pressure p_1, be able to discharge all the steam by lifting 1-36th part of its diameter.

At absolute pressures of 72 lbs., the British and Prussian laws prescribe precisely the same area of valve.

Take, for example, 20·36 square feet of fire grate, which requires by British rule a valve 10·18 square inches in area, equal to 3·6 inches diameter, and which if flat-faced would, at a pressure of 72 lbs., require to lift $\frac{2 \times 3{\cdot}6}{72}$ equal to 1-10th of an inch.

Then, by the Prussian rule the area of valve is, for 20·36 feet of grate and 72 lbs. pressure: $a = \frac{36 \times 20{\cdot}36}{72} = 10{\cdot}18$ square inches = 3·6 inches diameter; and the requisite lift is (diameter 3·6) as before $= \frac{3{\cdot}6}{36} =$ 1-10th of an inch. The circumference of this valve being 11·31 inches, would (if flat-faced) by lifting 1-10th inch give a clear opening of 1·131 square inch, which opening would, at 72 lbs. pressure, discharge $\frac{3}{4} \times 72 \times 1{\cdot}131 = 61{\cdot}07$ lbs. of steam per minute, and which corresponds to 3 lbs. per foot of fire grate—as, $20{\cdot}36 \times 3 = 61{\cdot}08$.

At absolute pressures of 36 lbs. the Prussian law prescribes double, and at 144 lbs. only half the area of the British.

At all pressures above 1·726 atmosphere, the *area* of valve when full open, by Prussian rule, is nine times that requisite to discharge all the steam generated, while by British rule it is 4½ times at 36 lbs. pressure, and 18 times more than is required at 144 lbs. absolute pressure; and this is after allowing for an evaporation of 3 lbs. of water per minute per square foot of fire grate, which is considerably more than is usually realized in marine practice.

Before the ordinary valves rise and give sufficient opening, the pressure of steam frequently greatly exceeds the load under which the valve begins to rise. Hence the requirement of large areas. With a properly constructed valve, however, such as many now in use, which rise one-fourth of their diameter by an increment of 1 to 3 lbs. above the load, there is no necessity for the area being much (if any) more than 1-9th of that prescribed by the Prussian rule. Say, area $a = \frac{4 \times \text{square ft. of grate}}{p_1}$ plus the area of wings of valve. The valves here referred to are so very small that the stems, or wings, occupy a considerable proportion of the area, and must in the above equation be allowed for. Those small valves give much more prompt relief to the boiler, and never permit the pressure to rise much beyond the load.

"RESULT OF A SERIES OF EXPERIMENTS, made to ascertain the increase of pressure in a boiler when all the steam raised was allowed to pass away by the safety valves unassisted.—Two valves were used, the united area of which was half an inch per foot of grate surface. The boiler used was tubular, with 2 furnaces; the grate surface was 25 square feet; the heating surface 746 square feet. The valves were each 2⅞ inches diameter, the fuel used was ordinary good Glasgow dross, the firing good, and as nearly uniform during all the experiments as possible. The valves were loaded by direct weights. On next page we give table of results.

With flat-faced valves having, according to Board of Trade rule, half of one square inch area per foot of fire grate, $W = \frac{3\,P\,L}{2\,D}$.

But the valve seats being to an angle of 45 degrees,

$W = \frac{3\,P\,L}{2 \cdot 8\,D}$ = Weight of steam discharged per minute per square foot of fire grate.

P = Absolute pressure in lbs. per square inch.

D = Diameter of valve in inches.

L = Lift of valve in inches.

Load on Valve.	Press. rose to	Incr. per cent.	Lift of Valve.	W. Lbs.
5 lbs.	13 lbs.	160·	·325	3·39
10 ,,	19 ,,	90·	·255	3·223
15 ,,	25 ,,	66·	·18	2·68
20 ,,	30 ,,	50·	·16	2·676
25 ,,	36 ,,	44·	·1425	2·7
30 ,,	40 ,,	33·	·1262	2·58
35 ,,	44 ,,	25·7	·1125	2·466
40 ,,	48½,,	21·	·103	2·437
45 ,,	52 ,,	15·5	·097	2·41

The guides of valve would reduce the clear opening by full one-ninth, for which no allowance has in the above been made.

Table showing the respective area of valve for the boiler in question, if made according to the committee's recommendation, as compared with present practice in this country, and at the several undernoted absolute pressures:—

Absolute Pressure of Steam.	Areas of Valve as recommended by Committee.	Areas of British Valves.
20 lbs.	45· square in.	12·5 square in.
25 ,,	36· ,,	12·5 ,,
30 ,,	30· ,,	12·5 ,,
35 ,,	25·7 ,,	12·5 ,,
40 ,,	22·5 ,,	12·5 ,,
45 ,,	20· ,,	12·5 ,,
50 ,,	18· ,,	12·5 ,,
55 ,,	16·36 ,,	12·5 ,,
60 ,,	15· ,,	12·5 ,,
65 ,,	13·84 ,,	12·5 ,,
70 ,,	13· ,,	12·5 ,,
75 ,,	12· ,,	12·5 ,,

Safety valves of ordinary construction, if loaded by direct weight, do not allow all the steam to escape which can be raised in the boiler until the pressure has increased above that at which the valve opens, and an additional increase of pressure will take place when the valves are loaded by springs. That such has been the case in the past by dead-weight loading and imperfectly proportioned valves is fully illustrated by reference to the foregoing experiments.

The object in appointing this committee was to investigate the cause of this increase of pressure, especially with boilers proportioned in strength to work at low pressures, and it is hoped that the result of these investigations will clearly show that the great cause

lay in using valves of too small dimensions; and that with valves proportioned as proposed, properly constructed and loaded by springs, anything approaching a dangerous increase of pressure is entirely avoided.

"On Loading Safety Valves by Direct Springs.—It has been shown that valves having half an inch of area per square foot of grate surface require to lift $\frac{2 \times \text{diameter of valve}}{P}$ in order perfectly to relieve the boiler; and if proportioned as is recommended in this report, then the lift would be in all cases $\frac{\text{diameter of valve.}}{36}$

Having determined the requisite lift, it remains to fix any reasonable or desired per centage of the load, which is not to be exceeded by the additional load due to the compression or extension of the spring, caused by the lift of the valve. Let this, for example, be restricted to $2\frac{1}{2}$ per cent. of the original load.

Then the spring loading the valve should be so proportioned that the compression or extension, to produce the initial load, shall be 40 times the lift of the valve.

So that with valves having half an inch area per foot of grate surface, the initial compression or extension of spring would be $= \frac{80 \times \text{diameter of valve}}{P}$. With valves as recommended, the initial compression or extension would be $1 \cdot 11 \times$ diameter of valve. The following formula refers to spiral springs, made of steel in the usual way:—

E = Compression or extension of one coil in inches.

d = Diameter from centre to centre of steel composing spring in inches.

w = Weight applied in pounds.

D = Diameter or side of square of steel of which the spring is made in 16ths of an inch.

C = A constant which, from experiments made, may be taken as 22 for round steel and 30 for square steel.

$$E = \frac{d^3 \times w}{D^4 \times C}.$$

The total compression or extension of such a spring is equal to that of one coil into the number of effective coils, which may be taken as two less than the apparent number, the end coils

being usually flattened to serve as bases for the spring to rest upon.

The relation between the safe load, size of steel, and the diameter of the coil has been deduced from the works of the late Professor Rankine, and may be taken for practical purposes as follows:—

$$D = \sqrt[3]{\frac{w \times d}{3}} \text{ for round steel.}$$

$$D = \sqrt[3]{\frac{w \times d}{4{\cdot}29}} \text{ for square steel.}$$

The application of the above formulæ may be illustrated by the following calculations of three different proportions of springs, all designed to give the same result. Diameter of valve, 4″ = 12·5 area in square inches. Boiler pressure 60 lbs. per square inch. Omitting weight of valve, spindle, and spring; load required = 12·5 × 60 = 750 lbs. Then, assuming that this valve is in the proportion of half a square inch area per foot of grate surface, the lift of valve would be $= \frac{2 \times 4}{75} = {\cdot}106$, say ·1″.

Initial compression of spring, $\frac{80 \times 4}{75} = 4''{\cdot}26$, say 4 inches.

1st. Supposed diameter of spring, or *d*, equal 4 in. $D = \sqrt[3]{\frac{750 \times 4}{3}} = 10$, diameter of spring steel = 10-16ths. $E = \frac{64 \times 750}{10000 \times 22} = {\cdot}218''$. Effective number of coils $= \frac{4}{{\cdot}218} = 18{\cdot}3$, say 18. Pitch of spiral, allowing between each coil a distance equal to twice the intended compression = 1″·061, say 1 inch; effective length of spring = 18 × 1 = 18″, and allowing for two end coils as bases, say 19½″, = the length of spring before compression.

2d. Supposed diameter of spring, 6 in. $D = \sqrt[3]{\frac{750 \times 6}{3}} = 11{\cdot}447$, say 12-16ths. $E = \frac{216 \times 750}{20736 \times 22} = {\cdot}355''$. Effective number of coils required, $\frac{4}{{\cdot}355} = 11{\cdot}2$, say 11. Pitch of spiral, 1·46″; effective length of spring, 1·46 × 11 = 16·06″, and allowing for two end abutment coils, say 17½″ = the length of spring before compression.

3d. Supposed diameter of spring 12 in. $D = \sqrt[3]{\frac{750 \times 12}{3}} = 14{\cdot}42$, say 14-16ths. $E = \frac{1728 \times 750}{38416 \times 22} = 1{\cdot}533''$. Effective number of coils required, $\frac{4}{1{\cdot}53} = 2{\cdot}61$. Pitch of spiral, 3·9″; effective length of spring,

$3{\cdot}9 \times 2{\cdot}61 = 10{\cdot}17''$, say $10''$, and allowing for two end abutment coils, say $11\frac{3}{4}''$ = the length of spring before compression.

In cases where it is desirable or perhaps necessary to employ springs acting at the ends of levers, the same formulæ can be employed for determining the proportion of springs, bearing in mind that the lift of the end of the lever where the spring is attached, is to be taken instead of the simple lift of valve.

The above illustrative calculations have all reference to springs made of round steel, and used in compression. In many cases two or more springs, one within the other, may be used with advantage.

After consideration of the whole of the experimental information obtained, and the necessities required in practice, the committee have come to the following conclusions:—

1st. The present practice in this country of constructing safety valves of uniform size for all pressures is incorrect.

2d. The valves should be flat-faced, and the breadth of face need not exceed one-twelfth of an inch.

3d. The present system of loading valves on marine boilers by direct weight is faulty, and ill adapted for sea-going vessels, a considerable quantity of steam being lost during heavy weather, in consequence of the reduced effect of direct load—the result of the angle or list of the vessel, and also of the inertia of the weight itself, the latter not being self-accommodating at once to the downward movements of the vessel, and, moreover, the impossibility of keeping the valves when so loaded in good working order.

4th. That two safety valves be fitted to each marine boiler, one of which should be an easing valve.

5th. The dimensions of each of these valves, if of the ordinary construction, should be calculated by the following rule:—

$$A = \frac{18 \times G}{P} \text{ or } A = \frac{0{\cdot}6 \times H\,S}{P}$$

A = Area of valve in square inches.
G = Grate surface in square feet.
H S = Heating surface in square feet.
P = Absolute pressure in lbs. per square inch.

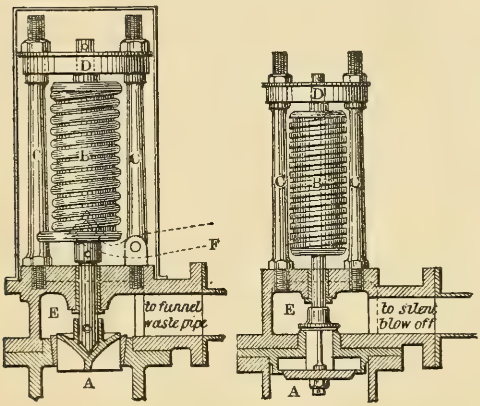
6th. The committee suggest that only one of the valves may be of the ordinary kind, and proportioned as above, and that it should be the easing valve. The other may be so constructed as to lift one quarter of its diameter without increase of pressure. Valves of this kind are now in use, and one such valve, if calculated by

the following rule, would be of itself sufficient to relieve the boilers:—

$$A = \frac{4 \times G}{P} + \text{area of guides of valve,}$$

$$\text{Or } A = \frac{\cdot 133 \times H\,S}{P} + \text{area of guides of valves.}$$

This valve should be loaded, say 1 lb. per square inch, less than the easing valve.



Figs. 348A, 348B.—A, Safety valve. B, Spring. C C, Studs with screwed ends. D, Cap. E E, Chest leading to waste pipe and nozzle at the side of ship. F, Hand lever for lifting valve.

7th. As experience in the use of valves of this description is acquired, both may be of this kind, and one of them made to blow into the sea without any increase of pressure, as is illustrated by the diagrams (Figs. 348A—348C) from actual practice; the other to be the easing valve, and loaded 1 lb. per square inch in excess of the working valve.

8th. If the heating surface exceeds 30 feet per foot of grate surface, the size of safety valve is to be determined by the heating surface.

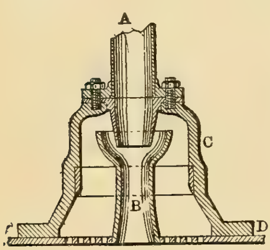


Fig. 348C—Section of Silent Blow-off Nozzle on Ship's side. A, Pipe from safety valve. B, Nozzle. C, Nozzle chest. D, Ship's side.

9th. As boilers decay from age it is necessary gradually to reduce the pressure of steam, and the committee recommend that valves should be made of a size to suit the pressure to which the boiler may ultimately be worked when it becomes old.

10th. Springs should be adopted for loading safety valves, and they should be direct-acting where practicable.

When levers are used, the friction of the joints will cause an extra resistance, and consequent increase of pressure, when the valve is rising, and a loss of steam through diminution of pressure before it will close."